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EFFECTS OF SHADING AND DEFOLIATION ON THE TURNOVER OF ROOT AND NODULE TISSUE OF PLANTS OF *Trifolium repens, Trifolium pratense,* AND *Lotus uliginosus*

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(*Received for publication, 21 January 1959*)

Summary

White clover, red clover, and a lotus species were grown in glass-sided boxes and the effects of recurrent defoliation and of shading on the growth of roots and nodules were observed.

With white clover, shading led to marked loss of both roots and nodules with little subsequent new growth. Under recurrent defoliation, however, the loss of roots and nodules was more than counterbalanced by new growth, leading to a rapid turnover of root and nodule tissue.

With red clover, the loss of roots and nodules was slower. There was no regrowth in the shaded plants and little in the recurrently defoliated plants, leading to a smaller turnover of root and nodule tissue than with white clover.

With lotus there was a rapid loss of nodules and some roots in both treatments, with only slight regrowth in the defoliated plants.

INTRODUCTION

The agronomic studies of Sears and co-workers (Sears 1953; Sears *et al.* 1953) and Walker *et al.* (1954) have shown that under New Zealand climatic conditions, as much as 100 lb nitrogen per acre may be transferred underground from white clover to an associated grass during the first year of establishment of a ryegrass/clover pasture. In subsequent years, the amount of nitrogen transferred may be as high as 200 lb per acre. Red clover has been observed to be markedly inferior to white clover as a nitrogen donor (Sears 1953).

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Butler and Bathurst (1956) reviewed the literature relating to the mechanism of donation of nitrogen by the legume to grass in legume/grass associations. They described experiments which rendered unlikely the widely-held view that excretion in quantity of simple nitrogenous compounds occurs from the nodulated root systems of the clovers. They reasoned that the rates of decay of nodules and roots were probably adequate to explain the nitrogen transfer. In the present paper this mechanism of transfer has been further studied. With the use of glass-sided boxes, observations have been made on the effects of defoliation and shading on the growth and decay of the nodulated root systems of white clover (*Trifolium repens* L.), red clover (*Trifolium pratense* L.) and lotus (*Lotus uliginosus* Schkuhr.).

Experimental

Three boxes of the type shown in Fig. 1 were built, the dimensions being 32 in. long, 21 in. deep and 12 in. broad. A glass sheet formed one side of each box and was inclined at an angle so that there was a 9 in. width of soil at the top and 4 in. width at the bottom. Adequate drainage was provided. The interior wooden faces of the boxes were painted thickly with bitumastic paint as a preservative. The boxes were filled with a sandy soil having a low nitrogen content (0.03% N). Prior to each experiment, the sand was packed by repeated watering and finally watered with nitrogen-free nutrient solution. Some further nitrogen-free nutrient solution was applied during the seedling establishment of the clovers. All experiments were carried out in an unheated glasshouse. Except during observation of the root systems, the glass sheets were fully screened from light by hinged doors.

The following observations were made on the nodulated root systems:

(a) Change in root pattern, recorded by photographing at intervals.

(b) Persistence and change in colour of nodules present at commencement of treatments, and numbers of new nodules formed. Any nodules showing a pink colouration were considered to be fixing nitrogen. At each observation, individual nodules were identified by location on a two-dimensional grid.

The experiments were carried out over different periods, with seasonal differences in temperature, day length and light intensity. This has to be borne in mind in comparisons between species but it is thought that the contrasts in behaviour of the three species were not influenced greatly.

White Clover Experiment

Three clover seedlings (N.Z. certified) were planted in each box on 20 June 1956. The plants grew rapidly and roots soon showed against the glass sheets. Nodules were first observed on the visible portion of the root system on 10 September. By mid October the roots had reached the bottom of the glass sheets (Fig. 1) in all three boxes, and a large population of nodules was visible. The general root pattern consisted of a large number of relatively slender main roots descending

Fig. 1.—Glass-sided box showing root systems of white clover at the commencement of treatment.

vertically from the crown and stolons, each with numerous short laterals. From 18 October, the plants in one box were defoliated to a height of approximately $\frac{1}{2}$ in. at intervals of 11 days. On the same date, plants in a second box were subjected to continuous shading. The plants in the third box were left untreated (controls). Each defoliation involved the removal of the major portion of the herbage and was followed by vigorous regrowth to a height of about 4 in. Shading was effected by means of layers of scrim which reduced the light intensity by approximately 75%.

The most noticeable early changes in the root systems occurred in the shaded box. Here, fading of the pink colour of nodules was noticed three days after treatments began and this was followed by cessation of development of new nodules. The cortical tissues of many of the roots were observed to turn brown and over the next few weeks death of these roots and their associated nodules took place. There was very

slow regrowth of new stolon roots to replace the roots which had decayed (see Fig. 2B), this being matched by greatly reduced rate of herbage growth.

By contrast, in the box where the plants were periodically defoliated, there was little initial acceleration in the fading of nodules. Active regrowth of new leaves took place from the young stolons and at the same time new stolon roots grew rapidly and became heavily nodulated. With each defoliation some death of older roots and nodules occurred.

TABLE 1. EFFECTS OF DEFOLIATION AT 11-DAY INTERVALS AND OF SHADING OF WHITE CLOVER ON THE COLOUR OF THE NODULES AND THE NUMBER OF NEW NODULES FORMED

Treatment	Nodules Visible at Start of Treatment	Percentage of Original Nodules Pink at Different Stages During Treatment				New Nodules Visible on 16th day of Treatment
		0 days	6 days	16 days	42 days	
Defoliated	176	60	46	41	3	277
Shaded	192	74	4	0.5	1	17
Control	134	65	39	40	9	187

The appearance of the root systems 30 days after commencement of treatments is shown in Figs. 2A, B and C. In Table 1, the percentage of nodules which remained pink over the treatment period, and the numbers of new nodules visible 16 days after treatments began, are recorded. It will be seen from the photographs that the control plants had the greatest root mass 30 days after commencement of treatments. Yet from Table 1 it is seen that there were at least as many original nodules still pink 16 days after treatment on the defoliated plants. It seems, therefore, that regular defoliation did not impair the nitrogen-fixing capability of the white clover and may, in fact, have increased it. On the other hand, continuous shading had a marked depressing effect on the percentage of nodules still pink and on the number of new nodules visible on the 16th day. The number of original nodules remaining pink 42 days after commencement of treatments was less than 10% in all boxes, giving an indication of the period of active nitrogen fixation by individual nodules under these conditions.

Red Clover Experiment

Broad red clover seed was sown in the glass-sided boxes on 25 February 1957. The seedlings were later thinned to three well spaced plants per box. While the root systems grew strongly, some death of main roots occurred quite early, and the tap root pattern was thus lost. The plants then developed several main roots which arose near the crown and extended diagonally to vertically downwards, each carrying

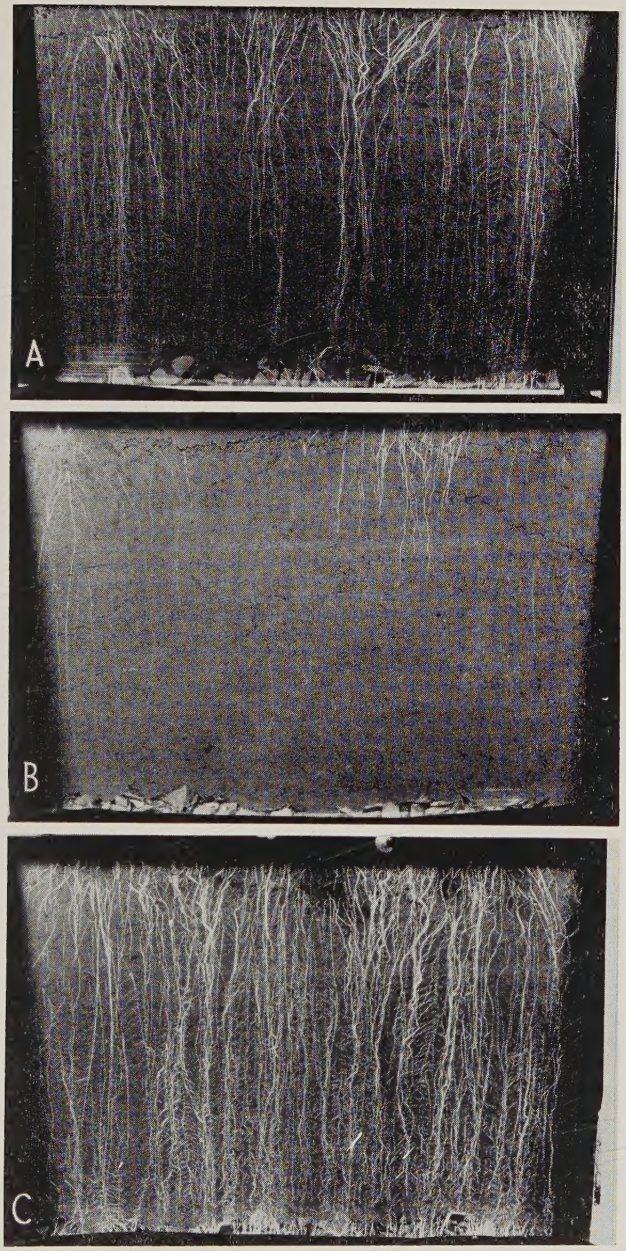


Fig. 2.—Root systems of white clover plants 30 days after commencement of treatments: *A* Defoliated, *B* Shaded, *C* Untreated.

a number of laterals. Many of these laterals later extended, some in time becoming main roots with higher-order laterals growing from them. The final root pattern thus obtained is similar to that found in the field.

By the end of May, up to 50 nodules were visible on some plants, but very few on others. Some decay of nodules had also occurred because of death of roots. Treatments were not begun until 13 August, by which time the main roots below the crown had become much thickened with development of storage tissue. There were still big differences in the number of nodules visible on different plants. From this date, plants in one box were defoliated at 12 day intervals, almost all leaf tissue but few terminal buds being removed at each defoliation. As with white clover, plants in the second box were shaded, while the plants in the third box were left untreated.

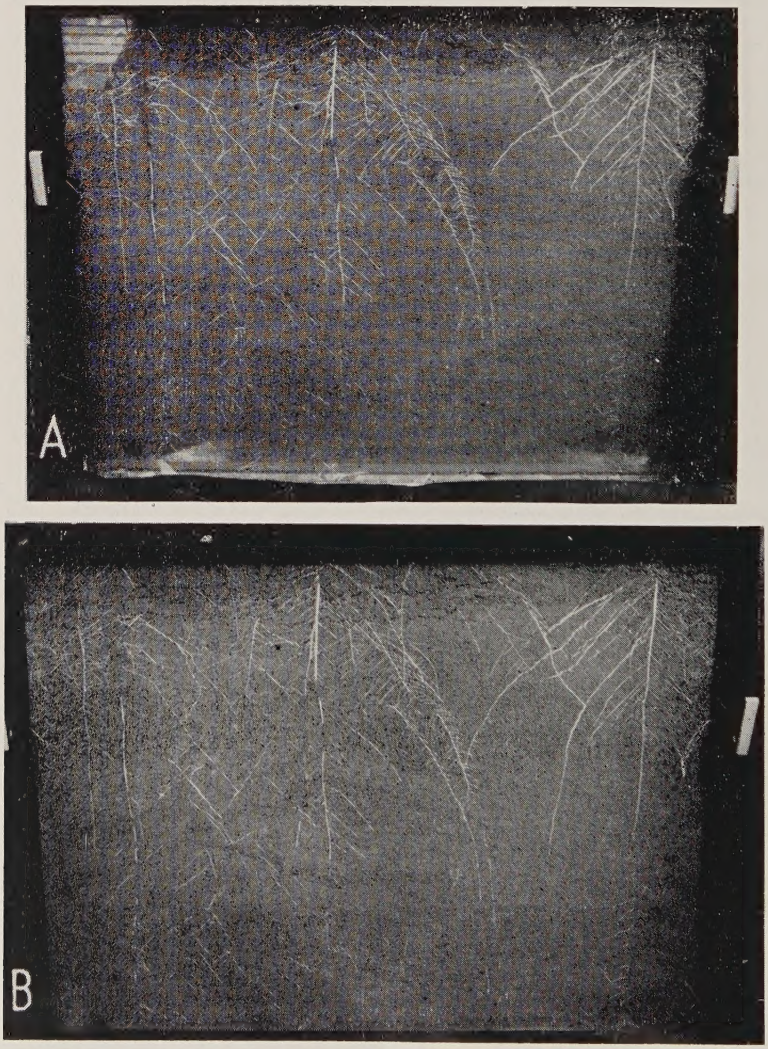


Fig. 3.—Root systems of defoliated red clover plants: *A* At commencement of treatments, *B* 37 days later.

The appearance of the root systems at the commencement of treatment and 37 days later is shown in Figs. 3A, 3B, 4A, 4B, 5A, and 5B respectively. Both treatments had little effect on the basic root pattern of this species, but were followed by widespread browning of roots and nodules. Regrowth of the defoliated plants was less vigorous than in the white clover experiment and, unlike the white clover, decreased with each defoliation. The rate of growth of herbage of the shaded plants was markedly retarded. Thirty-seven days after commencement

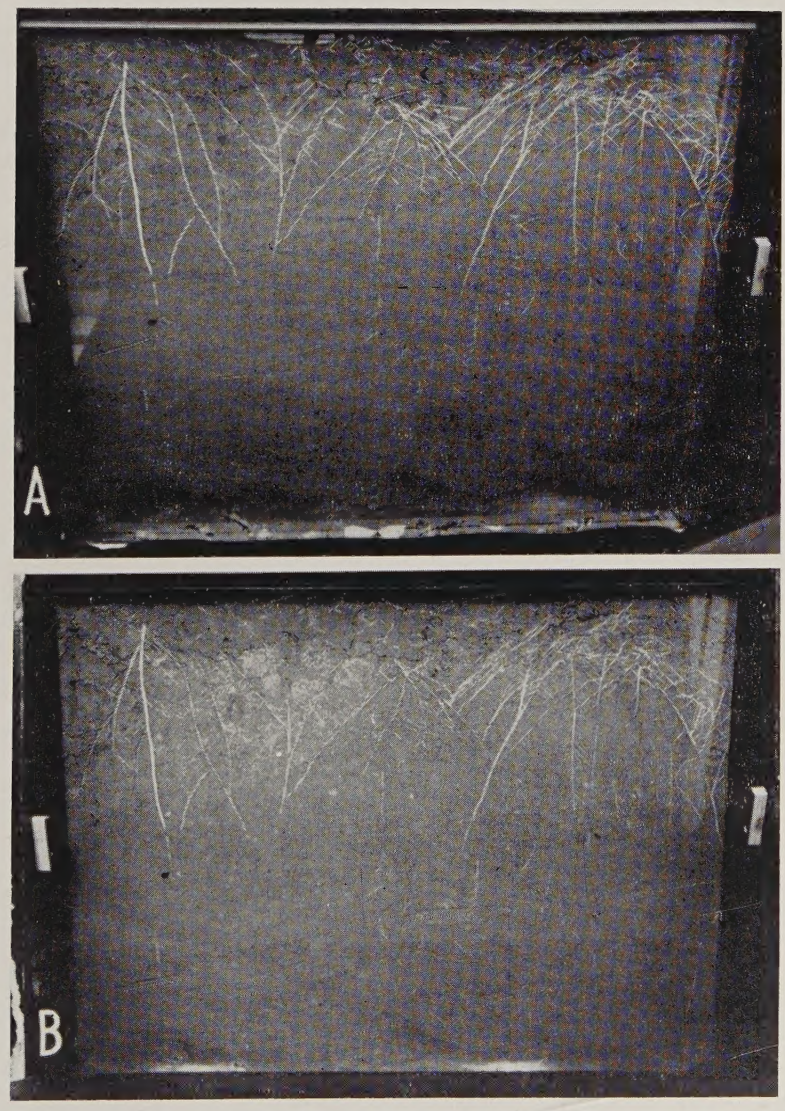


Fig. 4.—Root systems of shaded red clover plants: *A* At commencement of treatments, *B* 37 days later.

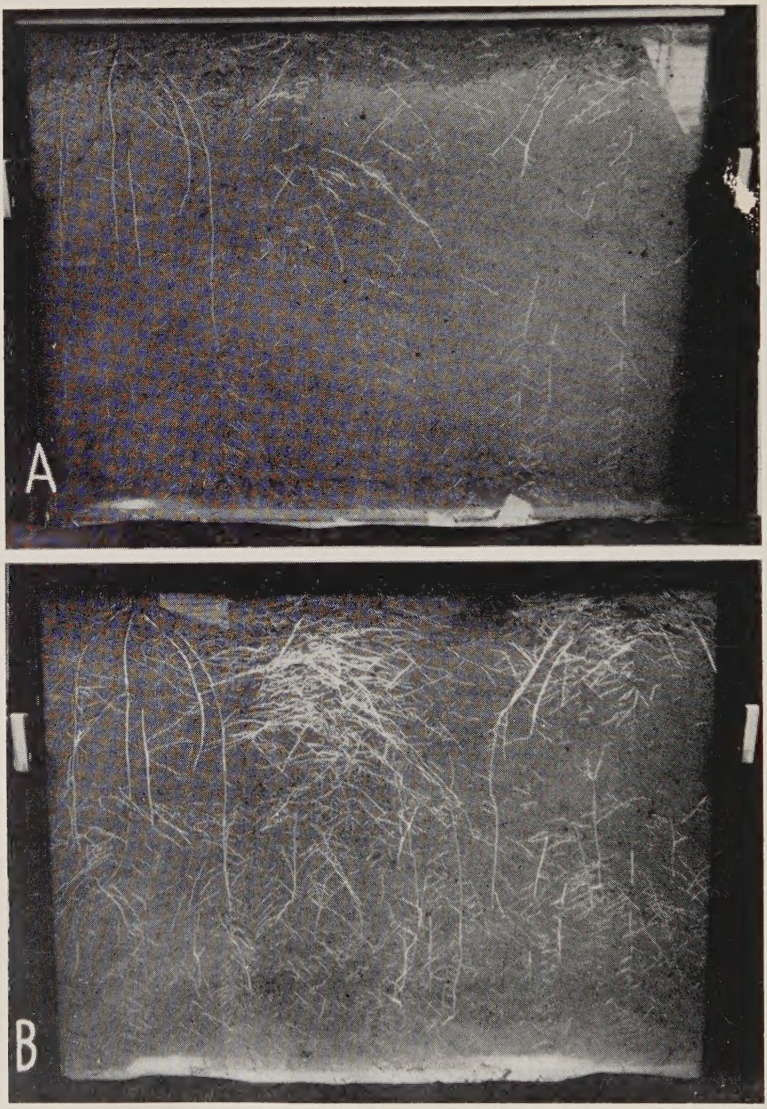


Fig. 5.—Root systems of untreated red clover plants: *A* At commencement of treatments, *B* 37 days later.

of treatments, no new roots had grown on the shaded plants and only a few slender brown roots on the defoliated plants.

In Table 2, the percentage of nodules which remained pink over the treatment period and the numbers of new nodules visible 37 days after commencement of treatments are shown. It will be seen that both treatments had a marked depressing effect on the percentage of pink nodules and the numbers of new nodules formed.

TABLE 2. EFFECTS OF DEFOLIATION AT 12-DAY INTERVALS AND OF SHADING OF RED CLOVER ON THE COLOUR OF THE NODULES AND THE NUMBER OF NEW NODULES FORMED

Treatment	Nodules Visible at Start of Treatment	Percentage of Original Nodules Pink at Different Stages During Treatment			New Nodules Visible on 37th day of Treatment
		0 days	11 days	37 days	
Defoliated	142	66	27	1	14
Shaded	157	37	19	0	0
Control	66	20	18	26	136+

Lotus Experiment

Two seedlings of *Lotus uliginosus* were planted in each box on 7 November 1957. In each box one plant was of a diploid strain, selected at Grasslands Division from plants of New Zealand origin: the other was of an induced tetraploid strain produced by colchicine treatment of the diploid (Barclay 1957). At the time of planting, the seedlings had some well-developed nodules near the crown. The plants grew rapidly and the roots soon reached the bottom of the boxes. The root pattern consisted of a number of equivalent roots arising near the crown and extending diagonally and vertically downwards, each carrying many short thin laterals. Apart from slightly thicker lateral roots in the tetraploid plants, there was little difference in root pattern or in later nodule development between these and the diploid plants. Nodules did not develop freely on that portion of the root system visible through the glass until January. The plants began to flower during January, and in order to keep them vegetative the buds were removed periodically.

On 31 January the plants in one box were defoliated, the greater part of the top growth being removed, and this was followed by a further defoliation 14 days later. Shading and control treatments were as in previous experiments. For the nodule observations, a grid was placed diagonally against each root system in turn, sample areas chosen, and all visible nodules noted within them.

Both shading and defoliation induced a rapid fading of the pink colour of the nodules. This effect was noticeable three days after the start of the treatments and was more marked in the shaded box. Subsequently the nodules became brown, as did the roots, and many of the laterals and some main roots died. There was also some death of main roots and laterals in the untreated box, but this was more than made up for by growth of new main roots and new laterals from the remaining old roots. By contrast there was no new root growth in the shaded box, and in the defoliated box there was not an appreciable amount of new growth until towards the end of the treatment period (31 days).

Table 3 gives the results of the nodule observations. It is seen that both defoliation and shading caused a marked depression in the percentage of pink nodules and no new nodules were formed.

TABLE 3. Effects of Defoliation at 14-day Intervals and of Shading of *Lotus uliginosus* on the Colour of the Nodules and the Number of New Nodules Formed

Treatment	Nodules Visible in Sample Areas at Start of Treatment	Percentage of Original Nodules Pink at Different Stages During Treatment			New Nodules Visible on 31st day of Treatment
		0 days	7 days	31 days	
Defoliated	94	100	10	0	0
Shaded	83	100	6	0	0
Control	85	100	95	36	61

Discussion

A comparison of the results of the three experiments reveals both similarities and differences in the reactions of the three legumes to shading and defoliation. Shading brought root growth almost or completely to a halt in all three species. Defoliation, however, produced differences in reaction which appeared to be more or less directly related to the growth form or to the possible availability of reserve materials of each species. The striking feature of the white clover experiment was the extent of the turnover of root and nodule tissue in the plants subjected to the repeated defoliations. This turnover resulted from the progressive death of older roots and nodules and their rapid replacement by new stolon roots which became heavily nodulated.

In contrast, the root systems of red clover showed slower initial changes with both treatments, probably because of the larger root reserves present. Also, presumably because of inherent limitations to regrowth determined by the growth form of this species, recurrent defoliation resulted in progressively poorer regrowth.

With lotus, still a different picture was seen. The plants reacted as quickly to the treatments as did white clover, but showed a slower capacity for recovery.

Since both shading and defoliation will reduce the carbohydrate supply to the root systems, it is not surprising that the reaction of plants to these treatments should include the partial or complete stoppage of root growth and the premature senescence and decay of root tissues. The effects of defoliation of grass have been reported by Crider (1955), Scott (1956) and Troughton (1957), and effects of shading by Harrison (1934), Watkins (1940), Mitchell (1954, 1955), Mitchell and Coles (1955), Soper (1957) and Troughton (1957). Both treatments caused

partial or complete stoppage of root growth and the premature senescence and decay of root tissues. With the legumes, on the other hand, emphasis has been placed on the decay and sloughing of nodules, rather than on senescence and decay of both root tissues and nodules (Strong and Trumble 1939; Wilson, P. W. 1940; Wilson, J. K. 1942; Butler and Bathurst 1956). In these experiments, however, decay of nodules was always seen to be associated with root decay. It should be remembered, however, that the nodules near the crowns of the plants were not visible (cf. Wilson 1942). The latter, using younger white clover plants without stolon roots, observed sloughing of nodules near the crowns after defoliation.

These experiments show that under recurrent defoliation, the root systems of all three legumes undergo a cyclic pattern of decay and renewal. With white clover, however, because of its stoloniferous growth habit, and its capacity for vigorous regrowth, the turnover of root and nodule tissue is much more extensive than with the other two legumes. In an association of grass and white clover, therefore, the turnover of leguminous root and nodule tissue presumably leads to a greater availability of nitrogen to the grass than where either red clover or lotus is the legume involved. Although these experiments were carried out under highly artificial conditions, they are consistent with the results already observed in the field. It appears that white clover, the most useful donor of nitrogen to associated grasses, requires defoliation and ample light to fulfill this role to the maximum in mixed pastures.

Acknowledgement

The writers are indebted to Mr. H. Drake, Photographer, Department of Scientific and Industrial Research, for the photographs.

References

Barclay, P. C. 1957: Improvement of *Lotus uliginosus*. *Proc. 19th N.Z. Grassl. Ass. Conf.* p. 75.

Butler, G. W.; Bathurst, N. O. 1956: The Underground Transference of Nitrogen from Clover to Associated Grass. *Proc. 7th int. Grassl. Congr.*, p. 168.

Crider, F. H. 1955: Root-growth Stoppage Resulting from Defoliation of Grass. *Tech. Bull. U.S. Dep. Agric. 1102.* 23 pp.

Harrison, C. M. 1934: Responses of Kentucky Bluegrass to Variations in Temperature, Cutting and Fertilising. *Plant Physiol. 9:* 83.

Mitchell, K. J. 1954: Influence of Light and Temperature on Growth of Ryegrass (*Lolium* spp.). III. Pattern and Rate of Tissue Formation. *Physiol. Plant 7:* 51.

——— ——1955: Growth of Pasture Species. II. Perennial Ryegrass (*Lolium perenne*), Cocksfoot (*Dactylis glomerata*) and Paspalum (*Paspalum dilatatum*). *N.Z. J. Sci. Tech. A37:* 8.

Mitchell, K. J.; Coles, S. T. J. 1955: Effects of Defoliation and Shading on Short-rotation Ryegrass. *Ibid. A36:* 586.

Scott, J. D. 1956: The Study of Primordial Buds and the Reaction of Roots to Defoliation as the Basis of Grassland Management. *Proc. 7th int. Grassl. Congr.* p. 479.

Sears, P. D. 1953: Pasture Growth and Soil Fertility. I. *N.Z. J. Sci. Tech. A35 (Suppl. 1):* 1.

Sears, P. D.; Lambert, J. P.; Thurston, W. G. 1953: Pasture Growth and Soil Fertility. VI. *Ibid. A35:* 199.

Soper, Kathleen 1957: Effects of Changes in Light and Temperature on Roots of Perennial Ryegrass (*Lolium perenne* L.). *Ibid. A38:* 783.

Strong, T. H.; Trumble, H. C. 1939: Excretion of Nitrogen by Leguminous Plants. *Nature, Lond., 143:* 286.

Troughton, A. 1957: "The Underground Organs of Herbage Grasses," pp. 84-102. Commonwealth Agricultural Bureau, England.

Walker, T. W.; Orchiston, H. D.; Adams, A. R. F. 1954: The Nitrogen Economy of Grass Legume Associations. *J. Brit. Grassl. Soc. 9:* 249.

Watkins, J. M. 1940: The Growth Habits and Chemical Composition of Bromegrass, *Bromus inermis* Leyss., as Affected by Different Environmental Conditions. *J. Amer. Soc. Agron. 32:* 527.

Wilson, J. K. 1942: The Loss of Nodules from Legume Roots and its Significance. *J. Amer. Soc. Agron. 34:* 460.

Wilson, P. W. 1940: "The Biochemistry of Symbiotic Nitrogen Fixation," pp. 114-41. Univ. of Wisconsin Press, Madison.

EFFECT OF PHOSPHATE TOPDRESSING ON A SOIL FROM ANDESITIC VOLCANIC ASH

I. FORMS OF SOIL PHOSPHORUS AND A METHOD FOR THEIR DETERMINATION

By W. M. H. Saunders, Soil Bureau, Department of Scientific and Industrial Research, Wellington

(*Received for publication, 15 December 1958*)

Summary

As an introduction to a method for fractionation of phosphorus in acid soils, the nature of soil phosphorus is discussed. Phosphorus in acid soils has been divided into three major categories, (a) organic phosphorus, (b) apatite phosphorus and (c) Fe- and Al-bound phosphorus.

Organic phosphorus may be determined by an alkaline extraction procedure or by an ignition method, the latter being the more rapid and simpler but more liable to error due to changes in the solubility of the inorganic phosphorus during ignition. Apatite phosporus is assumed to be the phosphorus not extracted by boiling 0.1 N NaOH after the exchangeable calcium has been removed. Fe- and Al-bound phosphorus is the difference between the total inorganic phosphorus and the apatite phosphorus. The experimental procedures are described and discussed.

Introduction

As part of a study of the phosphorus requirements of pastures on the yellow-brown loams of Taranaki, a comparison was made of soils collected from farms which used light and heavy rates of phosphate topdressing. This comparison necessitated the fractionation of the soil phosphorus and in this paper the procedure used is described and discussed. As an introduction to the method of fractionation and as a basis for later discussion of phosphate fixation in these soils a short survey has been made of the nature of soil phosphorus.

Categories of Soil Phosphorus

Primary Phosphorus

Primary soil phosphorus is represented by the forms of phosphorus that were originally present in the parent rock and may be present in the soil profile in sand and silt particles. The occurrence of phosphorus in rocks has been described by Rankama and Sahama (1950). Apatite ($Ca_{10}(PO_4)_6.X_2$, where $X = F^-$, Cl^-, OH^- or CO_3^{2-}, is the predominant form of phosphorus in igneous rocks. In sedimentary rocks a considerable proportion of the phosphorus still remains as unweathered apatite from igneous rocks and the remainder is present as forms of calcium phosphate. As the equilibrium products of $CaO—H_2O—CO_2—P_2O_5$ and $CaO—H_2O—P_2O_5$ systems tend toward the apatite structure (Basset 1917; Arnold 1950) it is possible that these calcium phosphates exist as finely divided forms of apatite. The occurrence of apatite in the sand and silt fractions has been proved

many times by microscopic examination. Williams and Saunders (1956a and b) considered, from phosphorus solubility studies on the mechanical fractions of some acid Scottish soils, that the phosphorus in the coarse and fine sand fractions was mainly calcium-bound as apatite. In these Scottish soils 34% to 80% of the inorganic phosphorus was present in the sand fractions. The rate at which apatite breaks down in acid soils depends on the soil pH, the rate of soil weathering, the nature of the apatite, the particle size and the degree to which the apatite is protected by inclusion within sand particles.

Secondary Phosphorus

Secondary forms of soil phosphorus are formed as part of soil development. They may occur in organic or inorganic forms and, in contrast to primary phosphorus, occur predominantly in the silt and clay fractions. Williams and Saunders (1956a) found practically all the organic phosphorus of some Scottish soils in the silt and clay and most of this was in the clay fraction. Both the nature of soil organic phosphorus and its mode of occurrence in soils are largely unknown. A short summary of the progress made on this problem is given here and the reader is referred to a review by Black and Goring (1953) for further information.

The organic phosphorus in soils can make up a very large proportion of the total soil phosphorus, especially in topsoils where it is common for it to be between 40% and 60% of the total phosphorus content. In general, the organic phosphorus level in soils follows that of the organic carbon and nitrogen. There are, however, a wide range of C:org.—P and N:org.—P ratios reported. This is probably mainly due to differences in the nature of the soil organic matter but some additional variation is probably also due to unreliable methods for determining organic phosphorus.

The problem of the identity of phosphorus compounds in soil organic matter has been approached by trying to identify in soil extracts organic phosphorus compounds which occur in plants and soil organisms. Three groups of compounds have been studied: phospholipids, nucleic acids, and inositol phosphates.

Phospholipids. This group of compounds is soluble in ether and alcohol and small amounts of organic phosphorus can be extracted from soils by these solvents. Aso (1905) identified choline, a hydrolysis product of lecithin, in soil extracts, and this is the only evidence of the nature of phospholipids in soils.

Nucleic Acids. The presence of nucleic acids in soils has been postulated from the identification of their hydrolysis products, pentose sugars, purine and pyrimidine bases, and phosphoric acid in soil extracts. Estimates of the proportion of the total soil organic phosphorus as nucleic acids have been made by Bower (1949) and Sokolov (1948) who separated nucleic acid fractions. Recently, however, Adams *et al.* (1954) using chromatographic methods examined a nucleic acid fraction similar to that of Bower and concluded that the soils examined contained very little nucleic acid.

Inositol Phosphates. The evidence for the presence of appreciable amounts of inositol phosphates in soil is stronger than that for the previous two groups. These organic phosphates have often been grouped under the name of phytin. Inositol has been identified in soil extracts and phytin fractions have been separated as the iron salt and identified by the P:Fe ratio (Bower 1949; Dyer *et al.* 1940; Wrenshall and Dyer 1941). Bower (1945) using the inositol:P ratio identified part of the "phytin fraction" as inositol hexaphosphate and the remainder as the lower derivatives. Smith and Clark (1951) separated a "phytin fraction" by a procedure similar to that of Bower and chromatographically analysed it. They found considerably less inositol phosphates than the previous workers. Recently Anderson (1956), after modifying the separating procedure, analysed the phytin fraction by paper chromatography and found that 27% to 38% of the organic phosphorus in some Scottish soils was inositol phosphates, the hexaphosphate predominating.

The identification of the organic phosphorus fraction of the soil is far from complete. How the organic phosphorus fraction occurs in soils, whether free or in combination with mineral constituents is not clear. Undoubtedly a part must be present in the bodies of soil organisms but this does not account for it all. Jackman and Black (1951, 1952a, b) have shown that inositol hexaphosphate is stabilised against enzymatic hydrolysis when precipitated by iron and aluminium in acid medium and by calcium in alkaline medium and have suggested that it is in these forms that phytin is stabilised in soils. However, until the constituents of the soil organic phosphorus are more fully identified this aspect can only be a matter of conjecture.

Secondary Inorganic Phosphorus

Because the nature of secondary inorganic phosphorus in a soil is determined by the factors governing phosphate retention, it is necessary and useful at this point to discuss phosphate retention.

The removal of phosphate from solution by reaction with the soil to form secondary inorganic phosphorus has been described by various terms. In this paper the terms used are as follows:

Retention is a broad term covering the removal of phosphate from the soil solution and its retention in the soil either by sorption or by fixation.

Sorption comprises adsorption, chemisorption, and absorption, referring to the retention of phosphate at the surface of or within the soil particles.

Fixation is retention of phosphate in forms unavailable to plants.

The products of the reaction between soils and phosphate in nature have not been identified, except for the isolated instance of secondary apatite on limestone particles after phosphate topdressing (Nagelschmidt and Nixon 1944). However a considerable amount of information as to their nature has been obtained indirectly from experiments in artificial systems. These experiments come under four headings:

(i) phosphate retention studies, in which phosphate retention by soils is compared with that by known compounds,

(ii) phosphate solubility studies, in which the changes in the solubility of soil phosphorus with pH are compared with those of precipitated and natural mineral phosphates,

(iii) increase or decrease of phosphate retention after the removal or addition of a soil constituent,

(iv) identification of phosphate compounds formed by the reaction of phosphate with soil constituents.

It is generally accepted that calcium, iron, and aluminium are the major elements occurring in soils that are concerned in phosphate retention, and that retention occurs to the greatest extent on the finest soil particles, the clay fraction (Dean 1949; Wild 1950; Williams, E. G. 1952). The extent of retention by any one of these elements depends on several factors of which pH is probably the most important.

The relationship between pH and phosphate in solution in the presence of iron, aluminium, and calcium has been extensively studied (Gaarder 1930; Doughty 1930: Mattson *et al.* 1951; Miller 1954; Stelly and Pierre 1942; Teakle 1928) and although there are some differences between individual reports as regards the exact pH ranges of minimum phosphate solubility, three generalisations can be made:

(i) In iron and aluminium systems the phosphate in solution is at its minimum between about pH 2 and pH 7.

(ii) In calcium systems the phosphate in solution is at its minimum above about pH 6.5.

(iii) The pH of minimum solubility in iron systems is about one pH unit lower than in aluminium systems.

In artificial systems and in soils where all three elements are present it is possible to obtain three separate phosphate solubility minima (Mattson *et al.* 1953). The relationship between the three forms of phosphorus may be expressed by the following equilibrium:

$$\text{Fe- and Al-bound P} \rightleftharpoons \text{Ca-bound P.}$$

Below pH 6.5 the equilibrium tends to the left, and above this pH to the right. The relationship is not, however, simply governed by pH alone and the extent to which the equilibrium moves at a given pH is modified by other factors such as, the absolute and relative amounts of Fe, Al, and Ca in the system, the form in which these elements are present, the ratio, Fe, Al, or Ca:P, the concentration and nature of electrolyte in the system, and the cation-exchange capacity of the soil. The rate at which the system moves to equilibrium is not necessarily rapid, as shown by the occurrence of large amounts of Ca-bound apatite phosphorus in the sand fractions of some acid soils (p. 428.) The manner in which these various factors affect the equilibrium is discussed below.

Ratio of Iron, Aluminium, or Calcium to Phosphorus. Gaarder (1930), Doughty (1930) and Miller (1954) have found that as the ratio Fe or Al:P increases, the amount of phosphate in solution de-

creases and the phosphate solubility minimum becomes wider and extends to a higher pH. For example Miller's results include a comparison of two aluminium phosphates which have Al:P molecular ratios of approximately 1 : 1 and 2 : 1. The pH-phosphate solubility curve of the 1 : 1 phosphate shows a phosphate solubility minimum at pH 4.1 and at this point the phosphate concentration in solution is about 0.6 mM/1. Minimum solubility for the 2 : 1 phosphate occurs between pH 4 and 6 and in this pH range the phosphate in solution is negligible. The curves of Gaarder and Doughty show the same trends but in these curves the presence of extra electrolyte must be taken into account as affecting the amount of phosphate in solution. Mattson *et al.* (1951) found a similar effect with a tertiary calcium phosphate when additional calcium was added as $Ca(OH)_2$. It is possible, in soils very high in iron and aluminium and low in calcium, that even above pH 6.5 the added phosphate is predominantly Fe- and Al-bound.

The width of the phosphate solubility minima (along the pH scale) depends on the absolute amount of phosphate in the system and sufficient may be added to increase the phosphate in solution and determine the pH of minimum phosphate solubility. However, to achieve these conditions it is usually necessary to use an amount of phosphate far in excess of that used under normal fertilising practices.

Nature and Amount of Electrolyte. This aspect of phosphate retention has been systematically studied by Mattson and his co-workers (Mattson *et al.* 1949, 1950a, 1950c, 1951, 1953; Miller 1954). They have found that the nature of the salt effect depends on whether the soil colloid has a net negative or positive charge, and that the extent of the salt effect depends on the concentration of the salt, the nature of its cation and anion and on the cation-exchange capacity of the soil colloid.

When the soil colloid is negatively charged, the distribution of the phosphate between the micellar solution surrounding the colloid particle, and the intermicellar or outer solution qualitatively obeys the Donnan theory and the concentration of phosphate in the outer solution is greater than in the micellar solution, the difference increasing as the negative charge on the colloid (cation-exchange capacity) increases. This is termed negative adsorption in contrast to the positive adsorption of cations on a negative colloid. The extent of negative adsorption increases with increasing cation-exchange capacity. The addition of a neutral salt to this system suppresses the Donnan distribution and the concentration of phosphate in the outer solution decreases until it finally equals that of the micellar solution. This suppression of the Donnan distribution, which appears as increased phosphate retention in the presence of added electrolyte, is a function of the cation of the salt and increases with increasing valency of the cation, i.e. Ca^{2+} ions have a greater effect than Na^{+} ions at equivalent concentrations.

When the soil colloid is positively charged, below its isoelectric point, phosphate ions become positively adsorbed and behave in a fashion analogous to cations on a negatively charged soil colloid. The phosphate is in this case exchangeable with other anions, the extent of the exchange depending on the relative concentrations and valency of

the anions. At this point it should be mentioned that some anions such as fluoride, citrate, oxalate, tartrate, and soil humate, which form stable complex ions with iron and aluminium, are able to displace phosphate both inorganic and organic from soils and reduce its retention above as well as below the isoelectric point.

Because of the amphoteric nature of soil colloids, retention of phosphate by soils passes through a point on the pH scale where there is zero salt effect. Above this pH, phosphate retention increases with added electrolyte, and below this pH phosphate retention decreases with added electrolyte. This point does not, however, coincide with the isoelectric point of the soil, but occurs at a higher pH. This is possibly due to the net negatively charged colloids being heterogeneous and having positively charged sites where phosphate retention is governed by simple anion exchange, although the overall distribution of the phosphate around the whole particle is governed by the Donnan equilibrium. This results in a higher pH of zero salt effect with increasing concentration and valency of the anion of the added salt.

For the wide range of acid soils studied by Mattson, the pH of zero salt effect with N Na_2SO_4 or KCl was below pH 6, the point decreasing as the acidoid:basoid ratio of the soil increased. In contrast, the pH of zero salt effect for a "tertiary" calcium phosphate was above pH 7, so that below pH 7 increasing electrolyte concentration in the soil solution would promote the release of Ca-bound phosphate and its subsequent retention by iron and aluminium.

Form of the Element. This factor involves some discussion of the mechanism of phosphate retention by soils. It is generally accepted that retention occurs by precipitation and by sorption, mainly chemisorption —that is, by reaction with iron, aluminium, or calcium ions in the soil solution or with these elements on the surface of soil particles. It is difficult, except in extreme cases, to distinguish between the two mechanisms and the difference tends to become rather arbitrary (Mattson *et al.* 1953).

Iron and Aluminium. It is well established that hydrous oxides of iron and aluminium and clay minerals are capable of rapidly removing large amounts of phosphate from solution and retaining them (Dean 1949; Midgley 1940; Wild 1950; Kurtz 1953). Some workers (Black 1942; Coleman 1942; Dean 1949; Haseman *et al.* 1950) consider that the lattice clay minerals themselves do not retain phosphate but that the rapid initial retention is due to closely associated sesquioxides. The electron-microscope studies of Kittrick and Jackson (1955, 1956) of the reaction between phosphate and soil constituents support this argument. However, in either case the phosphate becomes iron- or aluminium-bound. This retention is considered to be by sorption rather than by precipitation because of (a) the very rapid rate of retention and the very low concentration of Fe^{3+} and Al^{3+} in the soil solution, (b) the increase of phosphate retained with increasing phosphate added which follows the Freundlich adsorption equation (Russell and Prescott 1916; Davis 1935; Kurtz 1946; Low and Black 1950) and (c) because it appears that displacement of hydroxyl ions by the phosphate occurs (Ensminger 1948; Kelly and Midgley 1943; Murphy 1939; Stout 1939).

Calcium. Retention of phosphate occurs in the presence of $CaCO_3$ particles and this is considered to be by precipitation close to the surface by the calcium ions dissociated from the carbonate. (Boischat *et al.* 1950; Olsen 1953). Many studies have been made of the effect of exchangeable calcium on phosphate retention. Below pH 6.5, and as low as pH 4.0, it has been shown that calcium in the soil-phosphate system causes greater retention of phosphate than do monovalent ions such as sodium and potassium (Allison 1943; Pratt and Thorne 1948). It has been suggested that this is due to the formation of a clay-Ca-phosphate complex (Allison 1943: Barbier *et al.* 1946; Naftel 1936; Perkins 1947). An alternative explanation is available from the studies of Mattson and his co-workers mentioned above which does not require the specific bonding of phosphate by calcium in an acid system. Suppression of the Donnan distribution by added salt which appears as increased phosphate retention, is a function of the cation of the salt, and increases with its valency. Thus a calcium-saturated soil, with the soil solution containing Ca ions only, would retain more phosphate than a soil saturated with K or Na ions without specific Ca to phosphate bonds.

Olsen (1953) concludes that above pH 6.5 phosphate may be precipitated by calcium from the exchange complex. Mattson *et al.* (1953) have found that if the cation-exchange capacity is not fully saturated and the phosphate concentration is not excessive, exchangeable Ca does not retain phosphate even at pH 7–8. This has been confirmed in the present study and is reported later. Mattson *et al.* (1953) suggest that the phosphate is unable to compete with the cation exchanger for the calcium ion, and show that a Na-saturated cation exchanger is able to cause the dissolution of calcium phosphate by adsorption of Ca^{2+} ions.

To summarise: In moderately and strongly acid soils, below about pH 6.5 the secondary inorganic phosphate is Fe- and Al-bound mainly by sorption of the phosphate by iron or aluminium present as hydrous oxides and associated with the clay minerals, and to a small extent by reaction with iron and aluminium in solution. The evidence indicates that in acid soils, although a high exchangeable Ca content may increase phosphate retention, this does not require specific phosphate-to-calcium bonding. Retention of phosphate by calcium may occur in soils above about pH 6.5 by reaction with Ca^{2+} ions in solution which are derived from $CaCO_3$ and the cation-exchange complex.

The Possible Nature of the Binding of Secondary Inorganic Phosphorus

Isotopic exchange studies with ^{32}P (McAuliffe *et al.* 1947; Russell *et al.* 1954; Wiklander 1950; Olsen 1952) have indicated the possible nature of the binding of inorganic phosphorus in soils, both Fe- and Al-bound and Ca-bound. ^{32}P has been added to soil : water suspensions and the decrease of ^{32}P in solution with time noted. Initially there is a rapid loss of ^{32}P from solution as it exchanges very readily with ^{31}P on the soil. After the initial rapid exchange, the rate of exchange decreases as the ^{32}P exchanges with ^{31}P which is increasingly firmly bound. The continuous nature of these curves indicates a continuous change in the

strength of binding with no clear demarkation of different categories of the soil phosphorus.

Wiklander (1950) has suggested a useful schematic representation of the nature of secondary inorganic phosphorus in soils

$$P_S \rightleftharpoons P_Y \rightleftharpoons P_E \rightleftharpoons P_F$$

$$\Updownarrow$$

$$P_P$$

In this diagram the symbols represent:
P_S phosphate in the free soil solution
P_Y phosphate present as free ion in the micellar solution
P_E exchangeable phosphate adsorbed on the soil particle surface
P_F phosphate fixed in the interior of the soil particle
P_P phosphate precipitated as difficultly soluble compounds of Al, Fe, or Ca.

Wiklander's scheme has been modified here by taking P_E out of the micellar solution and considering that it is on the surface of the soil particle. This is only a schematic representation and, as mentioned above, the boundaries between categories probably are not sharply defined but are rather a gradual change from one category to another. The relative amounts of each category depend on the nature of the soil.

Wiklander assumes that the equilibrium between P_S and P_Y is governed qualitatively by the Donnan equilibrium and the equilibria between P_Y and P_E and between P_E and P_F by the general law of mass action. The equilibrium $P_S \rightleftharpoons P_P$ is controlled by constant solubility products.

In calcareous soils and soils above pH 6.5 the reaction $P_S \rightleftharpoons P_P$ predominates with the formation of Ca-bound phosphate. The calcium phosphates first formed become more basic by combination with further calcium ions and the ultimate product is probably a form of apatite (Basset 1917; Nagelschmidt and Nixon 1944; MacKintyre and Hatcher 1942).

In acid soils, where the added phosphate becomes Fe- and Al-bound, the process $P_S \rightleftharpoons P_Y \rightleftharpoons P_E \rightleftharpoons P_F$ predominates. When phosphate is added to the soil solution it is immediately distributed between P_S, P_Y, and P_E. The extent to which phosphate moves from P_S to P_E depends on the nature of the soil and in particular on the level of active iron and aluminium. Studies of phosphate-retention kinetics have shown that the initial very rapid reaction is followed by a much slower one which continues for months if not years (Hibbard 1937; Kurtz *et al.* 1946). Wiklander (1950) considers this slow reaction to be $P_E \rightleftharpoons P_F$. The nature of the secondary reactions is as yet unknown but may be the movement of phosphorus into the interior of the solid particle and a gradual change from amorphous disorder to subcrystalline and crystalline order. The products of these reactions are unknown

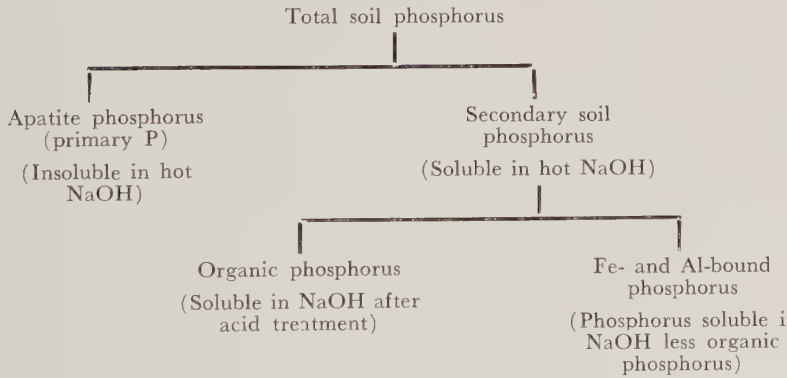
but the recent work of Cole and Jackson (1950a and b), Kittrick and Jackson (1956), Low and Black (1947, 1950), Ensminger (1948), and Haseman *et al.* (1950), in which crystalline products of the reaction between phosphate and soil constituents were identified, indicates their possible nature. It is unlikely, however, that the crystalline products which have been identified form as rapidly in the soil as in the artificial systems, first because the concentration of phosphate used in these artificial systems is very much greater than that found in soil solutions, and second because of the high temperatures generally used.

FRACTIONATION OF PHOSPHORUS IN ACID SOILS

In moderately to strongly acid soils such as the yellow-brown loams of New Zealand, Ca-bound phosphorus can be expected to occur only as apatite derived either from the parent rock or from added water-insoluble but acid-soluble fertilisers. The secondary inorganic phosphorus is Fe- and Al-bound. In these soils there are three major categories of soil phosphorus:

1. Organic phosphorus
2. Apatite phosphorus (primary)
3. Fe- and Al-bound phosphorus (secondary)

A method to determine these categories is outlined below


Total soil phosphorus
Apatite phosphorus (primary P)
(Insoluble in hot NaOH)
Secondary soil phosphorus
(Soluble in hot NaOH)
Organic phosphorus
(Soluble in NaOH after acid treatment)
Fe- and Al-bound phosphorus
(Phosphorus soluble in NaOH less organic phosphorus)

Organic Phosphorus

Dean (1938), Ghani (1943a) and C. H. Williams (1950), determined the organic-phosphorus content of soils as the difference between the total and inorganic phosphorus extracted by cold NaOH solutions. Their work and the more recent work of Mehta *et al.* (1954), Kaila and Virtanen (1955), and Saunders and Williams (1955), have indicated some of the factors which govern the extraction of organic phosphorus by alkaline solution.

Acid Pretreatment. Increased extraction of soil organic phosphorus is obtained if the soil is pretreated with an acid solution before the alkaline extraction. This pretreatment first removes exchangeable

calcium and $CaCO_3$ which apparently precipitate organic phosphorus during the alkaline extraction, but this is not the only factor involved, as pretreatment with N sodium acetate is not as effective as pretreatment with a dilute acid such as 2.5% acetic acid (Ghani 1943a). Increasing the severity of the acid treatment may result in greater extraction of organic phosphorus up to a point (HAc < cold 0.1 N HCl < hot 0.1 N HCl), but Saunders and Williams (1955) found that pretreatment with 4 N HCl (Wrenshall and Dyer 1939) gave lower organic-phosphorus values than pretreatment with hot 0.1 N HCl indicating hydrolysis of organic phosphorus during the strong acid treatment. The same authors found that when 8-hydroxyquinoline was added to the 2.5% acetic acid (C. H. Williams 1950), the acetic acid was equally effective as a pretreatment as the 0.1 N HCl. It is very probable, therefore, as C. H. Williams pointed out, that the pretreatment, besides removing active calcium, loosens the combination of the organic phosphorus with the mineral constituents such as Fe and Al either by a complexing action or by acid hydrolysis. Unfortunately, the 8-hydroxyquinoline interferes in the colorimetric determination of inorganic phosphorus and so prevents the determination of organic phosphorus extracted by the acid pretreatment. This could be appreciable.

Nature of Alkaline Extractions. NaOH is undoubtedly more effective for extraction of soil organic phosphorus than is Na_2CO_3 or NH_4OH (Bower 1945; Ghani 1943a; Mehta *et al.* 1954; Saunders and Williams 1955). Using NH_4OH, Pearson (1940) found that more organic phosphorus was extracted at 90°C than at room temperature. This was confirmed by Saunders and Williams (1955) but they also found that at 90°C some of the organic phosphorus extracted by NH_4OH was hydrolysed. In NaOH, the hydrolysis at high temperatures results in lower organic phosphorus values with hot than with cold extractions (Ghani 1943a). Ghani (1943a) and Saunders and Williams (1955) avoided this difficulty by making successive cold extractions. The method proposed by Mehta *et al.* involves very strong acid pretreatment followed by cold then hot NaOH extractions. A similar method has been described by Kaila and Virtanen (1955).

The superiority of one method over another can only be decided by which gives the higher organic phosphorus value, assuming of course that the analytical procedures are valid. Although the methods of Mehta *et al.* and Kaila and Virtanen are better than previous methods, there is the possibility of hydrolysis of organic phosphorus during the strong-acid pretreatment and a less drastic pretreatment may improve the organic-phosphorus value in some soils. There can be little doubt, as Kaila and Virtanen's results show, that the relative merits of the methods vary from soil to soil.

There is a second and very much simpler method for the determination, based on measuring the increase in the phosphorus soluble in acid after ignition of the soil and destruction of the organic matter. Unfortunately, it is open to criticism because changes may occur in the acid solubility of the inorganic phosphorus during the ignition. These changes in solubility have been noted with precipitated and natural

mineral phosphates but the extent to which they occur in soils has not been determined. In general, the organic phosphorus values by the ignition methods are higher than those by alkaline extraction (Legg *et al.* 1955; Kaila and Virtanen 1955; Saunders and Williams 1955). For some soils the ignition method values may prove satisfactory, as Saunders and Williams found for some acid Scottish soils. Legg *et al.* (1950) concluded for some Iowa soils that the ignition values were too high and reduced them by lowering the temperature of ignition. This was simply an arbitrary compromise between decreased extraction of organic-derived phosphorus and increased extraction of native inorganic phosphorus.

It is clear that the ignition methods are the more convenient, but it is advisable to check them against an alkaline extraction method. A comparison has been made between these two procedures using 18 samples of different total-phosphorus content from the New Plymouth black loam. The procedures used are essentially those described by Saunders and Williams, but with some modifications. The most important of these is the inclusion of a hot NaOH extraction in the alkaline extraction method.

Experimental Details

Alkaline Extraction. 0.5 g air-dried soil, < 100 mesh, was digested on a water bath for 1 hour with 25 ml 0.1 N HCl, transferred to a filter paper in a funnel and leached with small portions of hot 0.1 N HCl to give a total leachate of 100 ml.

The filter paper with soil was put in a 250-ml bottle and disintegrated by vigorous shaking with 200 ml 0.1 N NaOH and shaken end over end for 16 h. The suspension was filtered through a Buchner funnel under vacuum and the residue partially dried under suction. The extraction was repeated using 100 ml 0.1 N NaOH. For the hot NaOH extraction the paper pulp and soil were put in a 400 ml Erlenmeyer flask with 100 ml 0.1 N NaOH. The flask was stoppered with a bung fitted with double Bunsen valves and put in an oven at 90°C for 16 h. After the digestion the suspension was filtered.

Total and inorganic phosphorus in the acid and alkali extracts were determined colorimetrically and the organic phosphorus calculated as the difference between these two values.

Ignition Method. Two 0.5-g samples of air-dried soil (< 100-mesh) were weighed. One was put in a silica basin and ignited in a muffle furnace for 30 min at 500 to 550°C. The ignited and unignited samples were then shaken with 100 ml of N H_2SO_4 for 16 h and filtered. The inorganic phosphorus content of the two extracts was determined and the organic phosphorus value calculated as the difference between the two values.

Colorimetric Determination of Phosphorus. The procedure used was that of Williams and Stewart (1941) based on Truog and Meyer (1929). For total phosphorus, aliquots of the extracts were evaporated to dryness with 0.2 ml of 10% calcium acetate, ignited for 30 min at 500° to 550°C. When it had cooled, the residue was taken up in 10 ml

of 0.5 N H_2SO_4 digested for 1 h on a water bath, filtered into 100-ml volumetric flask, and the basin and filter paper washed with hot water till the total filtrate was about 60 ml. The pH of the filtrate was adjusted to between pH 5 and 6 using p-nitrophenol and then the blue colour developed. For inorganic phosphorus, an aliquot of the extract was put in a 100 ml volumetric flask, the volume made up to 60 ml and the pH adjusted if necessary. The dark colour in the alkaline extracts due to organic matter was removed by acidifying slightly, warming, filtering into a 100-ml volumetric flask and washing as many times as possible without getting too great a volume of filtrate. The pH was adjusted before the colour was developed.

Comparison of Methods

Tests. Tests showed that the hot NaOH extracted some organic phosphorus not soluble in the cold NaOH and in addition that 2 cold + 1 hot NaOH extractions gave slightly higher values than did 1 cold + 1 hot extraction. In view of the very high organic phosphorus content of these soils (100–175 mg P%) it was considered advisable to include the second cold NaOH extraction.

The method was compared with that of Mehta *et al.* (1954) for a few soils (Table 1).

TABLE 1. Organic Phosphorus Values by Alkaline Extraction Methods
(Expressed as mg P%)

Soil No.	1	2	3	4	5	6	7
Mehta	100	156	138	51	34	106	56
Saunders	103	156	136	59	43	127	64

The first three soils are from the same soil type and show no difference between the methods but in the remaining soils the present method has given higher values, indicating that it is at least equal to if not more satisfactory than that of Mehta *et al.*

In Table 2, the organic phosphorus values by the two methods are given for 18 samples of different total-phosphorus content from the New Plymouth black loam. For this soil the agreement between the two values is good, taking into consideration that the values are obtained as the difference between large values. The mean values by each method are 134 for the alkaline extraction and 133 for the ignition method. If the hot NaOH extraction had been omitted from the alkaline extraction procedure the ignition values would have been slightly higher which is what Saunders and Williams (1955) found for their soils from N.E. Scotland. In the comparison made by Legg and Black (1955), in which the ignition values were found to be appreciably higher, the alkaline extraction procedure used was that of Mehta *et al.* (1954). This latter method has been found to give lower values for a limited number of soils than the extraction method described above. These comparisons illustrate the uncertainties of the determination but

TABLE 2. COMPARISON OF ORGANIC PHOSPHORUS VALUES BY AN ALKALINE EXTRACTION METHOD AND BY AN IGNITION METHOD

(mg P/100 g oven-dry soil)

Soil No.	Alkaline Extraction			Ignition		
	Total P. Extd.	Inorg. P. Extd.	Org. P. Extd.	P. Extd. from Igntd Soil	P Extd from Air-dry Soil	Org. P
6378A	206	91	115	208	77	131
B	192	82	110	178	66	112
C	156	74	82	148	55	93
6379A	251	107	144	248	102	146
B	249	108	141	242	97	145
C	267	124	143	243	104	139
6380A	310	153	158	288	136	152
B	240	109	131	230	102	128
C	191	86	105	170	72	98
6382A	338	164	174	315	149	166
B	300	126	174	277	115	162
C	263	107	156	252	103	149
6383A	337	191	147	334	182	152
B	248	107	141	235	103	132
C	214	89	125	202	90	112
6384A	355	205	151	351	198	153
B	242	120	122	238	114	124
C	185	94	91	187	92	95

indicate that the values obtained by some igniton methods are a reasonably reliable estimate of the organic-phosphorus content. It is clearly necessary to use a strongly acid extractant, first to extract completely the mineralised organic phosphorus and second to extract as great a proportion as possible of the total inorganic phosphorus from the unignited sample in order to reduce errors due to increases in solubility of the inorganic phosphorus during ignition. At the same time, however, too strong an acid extractant may hydrolyse organic phosphorus. Until more is understood of the nature of organic phosphorus in soils, this determination must remain rather empirical.

Apatite Phosphorus

The direct determination of this category of soil phosphorus by extraction with acid is not satisfactory. Strong acid solutions (below pH 1) extract other categories and the use of dilute acids is complicated by incomplete dissolution of apatite phosphorus and by secondary sorption reactions (Russell and Prescott 1916; Ghani 1943; Williams and Saunders 1956b).

R. Williams (1937) divided soil phosphorus into two groups on the basis of its solubility in NaOH solution after exchangeable Ca had been removed. From solubility studies of known phosphorus compounds he concluded that only those having an apatite structure were insoluble in NaOH. This has subsequently been confirmed by Ghani (1943b) and C. H. Williams (1950). R. Williams suggested that the difference between the total soil phosphorus and the phosphorus soluble in NaOH would mainly represent apatite phosphorus but he thought some of the phosphorus insoluble in NaOH might be in other forms. He suggested titanium phosphate but C. H. Williams (1950) found this to be completely soluble in NaOH. Marshall (1935) suggested that some phosphorus may be held as an integral part of the clay mineral lattice, by isomorphous replacement of Si by P. He subsequently stated (1949) that such a replacement is unusual and that this is not surprising because phosphorus is a very minor constituent of the clay lattice. It would appear, therefore, very reasonable to believe that the soil phosphorus insoluble in NaOH consists of some form of apatite.

Experimental Details. The apatite phosphorus was assumed to be the difference between the total soil phosphorus and the phosphorus soluble in boiling NaOH. R. Williams' procedure for the determination of the latter value was modified and instead of a single extraction with 5% NaOH at a soil : solvent ratio of 1:20, successive extractions with 0.1 N NaOH (0.4%) at wider soil : solvent ratios were used. In the procedure adopted, 25 ml of N NaCl was added to 0. 5 g (< 100 mesh) air-dried soil in a beaker and allowed to stand for 15 minutes with occasional shaking. The soil was then washed into a filter paper and washed with N NaCl till the total volume of filtrate was 100 ml. The soil and paper were transferred to a 600-ml "pyrex" beaker, 200 ml 0.1 N NaOH added, and the suspension boiled gently for 3 h under a watchglass. Loss of water during the extraction was checked by reweighing the beaker and adding the necessary water. The soil residue was separated by filtering through a Buchner funnel. The extraction was repeated twice, using 100 ml instead of 200 ml of extractant.

The total phosphorus was determined in an aliquot of the combined NaOH extracts as described under the determination of organic phosphorus. The phosphorus in the NaCl leaching was found to be negligible.

The total soil phosphorus was determined according to Metson (1956) by digesting < 100-mesh soil with concentrated HNO_3 and HF, followed by Lorenz precipitation (Strzemienski 1955).

Fe- and Al-bound Phosphorus

This was assumed to be the difference between the total phosphorus soluble in NaOH and the organic phosphorus.

Discussion of Fractionation

This scheme for the fractionation of the soil phosphorus into the three major categories (Fig. 1) has been used to determine the effect of different rates of phosphate topdressing on the distribution of soil

phosphorus. The results of this work are discussed in Part II. These results, from 18 soil samples analysed in duplicate, have been used here to calculate the standard deviatons for each of the above categories. It has been found that the difference between duplicate analyses for each sample shows no tendency to increase with the size of the values and it is on this basis (that the error is constant over the range of values covered by the present soils) that the standard deviations have been calculated. The standard deviations and the mean values for the eighteen soils are shown in Table 3.

TABLE 3. STANDARD DEVIATIONS AND MEAN VALUES FOR FIVE CATEGORIES OF PHOSPHORUS
(mg P/100 g oven-dry soil)

	Standard Deviation	Mean Value for 18 soils
Total phosphorus content	2.0	254.5
Organic phosphorus		
(a) Alkaline extn. method	1.35	134
(b) Ignition method	1.45	133
Total phosphorus soluble in NaOH	4.9	239
Fe- and Al-bound phosphorus	5.1	106
Apatite phosphorus	5.3	15.5

Except for apatite phosphorus these figures show a satisfactory degree of reproductibility. In the present soils apatite phosphorus is present in only relatively small amounts and the error in its determination is unimportant.

The categories of soil phosphorus determined are similar to those separated in the scheme proposed by Ghani (1943a) and its simpler version used by C. H. Williams (1950), except that no attempt was made to determine a fraction of Ca-bound phosphorus soluble in dilute acid. This was because, as discussed above, retention of phosphate by calcium in acid soils is considered of no importance and residual apatite phosphorus is the only Ca-bound phosphorus present. The results of Russell and Prescott (1916) and Williams and Saunders (1956b) illustrate the complex nature of dilute acid extractions and that the final value may represent contributions from all the categories of inorganic phosphorus. A reagent such as citric acid, which contains an anion capable of forming complex ions with iron and aluminium, may also extract considerable amounts of organic phosphorus. The dilute acid used by Ghani and by Williams was 0.5 N acetic acid and to reduce secondary reactions between phosphate and iron and aluminium they included the complexing agent 8-hydroxyquinoline in the acid. However, because of its ability to complex with iron and aluminium, it is most probable that not only did it prevent reaction between phosphate and the iron and aluminium, but it released phosphate, both inorganic and organic, from combination with these elements. It is evident that

the dilute acid extraction, however modified, is no use for the determination of a single form of soil phosphorus although it may be useful for evaluating the relative levels of available phosphorus in soils.

The recent work in the determination of organic phosphorus in soils indicates that the single cold NaOH extraction used by C. H. Williams for the determination of organic phosphorus would generally give a low value. If a simple and rapid method for this determination is required, an ignition method is preferable.

The present fractionation makes no attempt to determine the nature or the strength of bonding within the categories of soil phosphorus. This would require special study. Some measure of relative levels of Al-bound phosphorus in soils is possible with a neutral ammonium fluoride extraction. Neutral 0.5 N ammonium fluoride does not appreciably attack apatite phosphorus in the sand fractions of soils (Dickman and Bray 1941; Williams and Saunders 1956c) and it releases Al-bound phosphorus to a much greater extent than Fe-bound phosphorus (Mattson *et al.* 1950b; Svenson *et al.* 1949; Williams and Saunders 1956c), apparently because of the greater stability of the AlF_6^{3-} ion in neutral and slightly alkaline solutions compared with the FeF_6^{3-} ion (Turner and Rice 1952). It can therefore serve as a useful guide to the relative levels of Al-bound phosphorus in different soils.

References

Adams, A. P.; Bartholomew, W. V.; Clark, F. E. 1954: *Proc. Soil Sci. Soc. Amer. 18:* 40-46.

Allison, L. E. 1943: *Soil Sci. 55:* 333-42.

Anderson, G. 1956: *J. Sci. Fd. Agric. 7:* 437-43.

Arnold, P. N. 1950: *Trans. Faraday Soc. 46:* 1061-72.

Aso, K. 1905: *Tokyo imp. Univ. Coll. agric. Bull. 6:* 277-84.

Barbier, G.; Chabannes, J.; Miallet, P. 1946: *Ann. agron., Paris, 16:* 7-33.

Basset, H. 1917: *J. Chem. Soc. 111:* 620-42.

Black, C. A. 1942: *Proc. Soil Sci. Soc. Amer. 7:* 123-33.

Black, C. A.; Goring, C. A. I. 1953: *Agronomy 4:* 123-52.

Boischat, P.; Coppenet, M.; Herbert, J. 1950: *Plant & Soil 2:* 311-22.

Bower, C. A. 1945: *Soil Sci. 59:* 277-85.

———1949: *Iowa agric. Exp. Sta. Res. Bull. 362.*

Cole, C. V.; Jackson, M. L. 1950a: *J. Phys. Chem. 54:* 128-42.

———1950b: *Proc. Soil Sci. Soc. Amer. 15:* 84-9.

Coleman, R. 1942: *Proc. Soil Sci. Soc. Amer. 7:* 134-8.

Davis, L. E. 1935: *Soil Sci. 40:* 129-58.

Dean, L. A. 1938: *J. agric. Sci. 28:* 234-46.

———1949: *Advanc. Agron. 1:* 391-411.

Dickman, S. R.; Bray, R. H. 1941: *Soil Sci. 52:* 263-73.

Doughty, J. L. 1930: *Soil Sci. 29:* 23-35.

Dyer, W. J.; Wrenshall, C. L.; Smith, G. R. 1940: *Science 91:* 319-20.

Ensminger, L. E. 1948: *Proc. Soil Sci. Soc. Amer. 13:* 170-4.

Gaarder, T. 1930: *Medd. Vestland, forstl. Forsöksta. 14:* 1-140.

Ghani, M. O. 1943a: *Indian J. agric. Sci. 13:* 29-45.

————1943b: *Ibid. 13:* 142-56.

————1943c: *Ibid. 13:* 562.

Haseman, J. F.; Brown, E. H.; Whitt, C. D. 1950: *Soil Sci. 70:* 257-72.

Hibbard, P. L. 1937: *Soil Sci. 39:* 337-58.

Jackman, R. H.; Black, C. A. 1951: *Soil Sci. 72:* 179-86.

————1952a: *Ibid. 73:* 117-25.

————1952b: *Ibid. 73:* 167-71.

Kaila, A.; Virtanen, O. 1955: *J. sci. agric. Soc. Finland 27:* 104-6.

Kelly, J. B.; Midgley, A. R. 1943: *Soil Sci. 55:* 167-76.

Kittrick, J. A.; Jackson, M. L. 1955: *Proc. Soil Sci. Soc. Amer. 19:* 292-5.

————1956: *J. Soil Sci. 7:* 81-9.

Kurtz, L. T. 1953: *Agronomy 4:* 59-88.

Kurtz, L. T.; De Turk, E. E.; Bray, R. H. 1946: *Soil Sci. 61:* 111-24.

Legg, J. O.; Black, C. A. 1955: *Proc. Soil Sci. Soc. Amer. 19:* 139-43.

Low, P. F.; Black, C. A. 1947: *Proc. Soil Sci. Soc. Amer. 12:* 180-4.

————1950: *Soil Sci. 70:* 273-90.

McAuliffe, C. D.; Hall, N. S.; Dean, L. A.; Hendricks, S. B. 1947: *Proc. Soil Sci. Soc. Amer. 12:* 119-23.

MacIntire, W. H.; Hatcher, B. W. 1942: *Soil Sci. 53:* 43-53.

Marshall, C. E. 1935: *J. Soc. chem. Ind., Lond. 54:* 1-5.

————1949: "Colloid Chemistry of the Silicate Minerals." p. 62. Academic Press, New York.

Mattson, S.; Eriksson, E.; Vahtras, K.; Williams, E. G. 1949: *Ann. R. agric. Coll. Sweden. 16:* 457-84.

Mattson, S.; Williams, E. G.; Eriksson, E.; Vahtras, K. 1950a: *Ibid. 17:* 64-91.

Mattson, S.; Williams, E. G.; Barkoff, E. 1950b: *Ibid. 17:* 107-20.

Mattson, S.; Alvsaker, E.; Koutler-Andersson, E.; Barkoff, E.; Vahtras, K. 1950c: *Ibid. 17:* 141-60.

Mattson, S.; Koutler-Andersson, E.; Miller, R. B.; Vahtras, K. 1951: *Ibid. 18:* 128-53.

Mattson, S.; Alvsaker, E.; Koutler-Andersson, E.; Vahtras, K. 1953: *Ibid. 20:* 19-50.

Mehta, N. C.; Legg, J. O.; Goring, C. A. I.; Black, C. A. 1954: *Proc. Soil Sci. Soc. Amer. 18:* 443-49.

Metson, A. J. 1956: Methods of Chemical Analyses for Soil Survey Samples. *N.Z. Soil Bur. Bull. 12.*

Midgley, A. R. 1940: *Proc. Soil Sci. Soc. Amer. 5:* 24-30.

Miller, R. B. 1954: *Ann. R. agric. Coll. Sweden 21:* 162-75.

Murphy, H. F. 1939: *Hilgardia 12:* 343-82.

Naftel, J. A. 1936: *J. Amer. Soc. Agron. 28:* 740-52.

Nagelschmidt, G.; Nixon, H. L. 1944: *Nature, Lond., 154:* 428.

New Zealand Soil Bureau 1954: *N.Z. Soil Bur. Bull. 5.*

Olsen, S. R. 1952: *J. phys. Chem. 56:* 630-2.

————1953: *Agronomy 4:* 89-122.

Pearson, R. W. 1940: *Industr. Engng. Chem. (Anal.) 12:* 198-200.

Perkins, A. T. 1947: *Proc. Soil Sci. Soc. Amer. 12:* 185-7.

Pratt, P. F.; Thorne, D. W. 1948: *Proc. Soil Sci. Soc. Amer. 13:* 213-7.

Rankama, K.; Sahama, T. G. 1950: "Geochemistry." Univ. Chicago Press.

Russell, E. J.; Prescott, J. A. 1916: *J. agric. Sci. 8:* 65-110.

Russell, S. R.; Rickson, J. B.; Adams, S. N. 1954: *J. Soil Sci. 5:* 85-105.

Saunders, W. M. H.; Williams, E. G. 1955: *J. Soil Sci. 6:* 254-67.

Smith, D. H.; Clark, F. E. 1951: *Soil Sci. 72:* 353-60.

Sokolov, D. F. 1948: *Pochvovedenie 8:* 505-13.

Stelly, M.; Pierre, W. H. 1942: *Proc. Soil Sci. Soc. Amer. 7:* 139-47.

Strzemienski, K. 1955: *N.Z. J. Sci. Tech. B37:* 243-57.

Stout, P. R. 1939: *Proc. Soil Sci. Soc. Amer. 4:* 177-82.

Swenson, R. M.; Cole, C. W.; Sieling, D. H. 1949: *Soil Sci. 67:* 3-22.

Teakle, L. J. H. 1928: *Soil Sci. 25:* 143-62.

Truog, E.; Meyer, M. O. 1929: *Industr. Engng. Chem. (Anal.) 1:* 136

Turner, R. C.; Rice, H. M. 1952: *Soil Sci. 74:* 141-8.

Wiklander, L. 1950: *Ann. R. agric. Coll. Sweden 17:* 407-24.

Wild, A. 1950: *J. Soil Sci. 1:* 221-38.

Williams, C. H. 1950: *J. agric. Sci. 40:* 233-42.

Williams, E. G. 1952: *Trans. int. Soc. Soil Sci. Dublin 1:* 31-47.

Williams, E. G.; Saunders, W. M. H. 1956a: *J. Soil Sci. 7:* 90-108.

———1956b: *Ibid. 7:* 189-202.

———1956c: *6th int. Congr. Soil Sci., 2:* 797-803.

Williams, E. G.; Stewart, A. B. 1941: *J. Soc. chem. Ind., Lond. 60:* 291-7.

Williams, R. 1937: *J. agric. Sci. 27:* 258-70.

Wrenshall, C. L.; Dyer, W. J. 1939: *Canad. J. Res. 17B:* 199-205.

——1941: *Soil Sci. 31:* 235-48.

EFFECT OF PHOSPHATE TOPDRESSING ON A SOIL FROM ANDESITIC VOLCANIC ASH

II. EFFECT ON DISTRIBUTION OF PHOSPHORUS AND ON RELATED CHEMICAL PROPERTIES

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Summary

A comparison has been made within a single soil type, New Plymouth black loam, of soils collected from farms that differed in their phosphate topdressing management: (a) not topdressed; (b) topdressed for 25 years at 20–30 lb P/acre/year; (c) topdressed for the last seven years at 60–80 lb P/acre/year.

Total, organic, apatite and Fe- and Al-bound phosphorus has been determined in these soils and also phosphorus soluble in dilute acids and neutral ammonium fluoride.

Phosphate topdressing has had little effect below 2 inches depth. In the 0–2 in. layer, it has resulted in large increases in the amount of Fe- and Al-bound phosphorus, phosphorus soluble in dilute acids and neutral ammonium fluoride, exchangeable calcium, and available phosphorus. There has been a small rise in the levels of apatite phosphorus and cation-exchange capacity, and the topdressing has had little or no effect on the soil pH and the level of organic matter and organic phosphorus. There has been a decrease in the amount of iron and aluminium extracted by sodium hydrosulphite. In each instance the change has been greater in the Heavy-P than in the Mod.-P soils, although the total amount of phosphorus added is similar for both soils.

It is considered that most of the accumulated phosphate has been Al-bound and that the very strong phosphate-retaining power of this soil is due to the high content of the amorphous clay allophane and associated amorphous oxides of iron and aluminium, and their very high specific-surface areas.

Introduction

The soils that cover most of the lowlands of the Taranaki province are developed on andesitic volcanic ash and are classified as yellow-brown loams (N.Z. Soil Bureau 1954). These soils are used for dairy and intensive sheep farming and are kept under practically permanent pasture. During the early days of settlement, the farmers found that phosphate fertilising was essential to maintain a good quality pasture. Without phosphate the newly sown pastures soon deteriorated into weeds and poor native grasses. During the 1920s the practice of phosphate topdressing increased and became a normal part of good pasture management on these soils.

Up to and including the 1939-45 war years, the normal rate of topdressing was between 15 and 30 lb P/acre/year. However, as a consequence of the demand for better-quality pastures, which developed during the war years, when greater supplies of phosphate became available after the war some farmers began to increase the amount of

Effect of Phosphate Topdressing on Cation-Exchange Capacity (CEC), Base Status, and pH

Cation-Exchange Capacity (Table 1)

The CEC was determined by the method described by Metson, using N ammonium acetate at pH 7, so that the results are directly comparable with the values obtained in the routine soil survey analyses. Birrell and Gradwell (1956) have shown the CEC of these soils to be dependent on the experimental conditions, especially the concentration of the exchanging cation, i.e. the ammonium ion.

TABLE 1. EFFECT OF PHOSPHATE TOPDRESSING ON SOME CHEMICAL PROPERTIES OF THE SOIL

Soils	Depth (in.)	pH	CEC me.%	TEB me.%	% BS*	Ex. Ca me.%	Ex. Mg me.%	Ex. K me.%	C %	N %	C/N	C/Org. P	N/Org. P
No-P (No phosphate added)	0–2	5.8	39.9	20.3	51	15.0	4.7	0.75	13.5	1.06	13	97	7.6
	2–5	5.6	35.3	13.1	37	10.4	2.5	0.50	11.3	0.95	12	87	7.4
	5–8	5.5	29.5	9.0	31	7.4	1.9	0.45	8.6	0.66	13	74	6.0
Mod.-P (20 to 30 lb. P/acre/year for about 25 years)	0–2	5.8	43.0	26.1	61	21.6	4.6	0.90	13.8	1.15	12	87	7.2
	2–5	5.8	35.3	18.0	51	14.8	1.7	0.45	11.0	0.92	12	76	6.3
	5–8	5.6	27.6	10.0	36	9.7	1.7	0.55	9.4	0.78	12	76	6.3
Heavy-P (60 to 80 lb. P/acre/year for 7 to 8 years)	0–2	6.1	46.6	35.9	77	30.2	5.0	1.00	14.4	1.06	14	94	6.9
	2–5	5.9	34.8	20.5	59	17.2	2.8	0.60	11.4	0.80	14	89	6.3
	5–8	5.7	25.6	8.9	35	8.3	1.8	0.55	9.0	0.58	16	86	5.6

$$* \ \% \text{ B.S.} = \frac{\text{TEB}}{\text{CEC}} \times \frac{100}{1}$$

The high cation-exchange capacities are typical of the yellow-brown loams and show the characteristic rapid decrease with depth. The CEC values for the 0–2-in. samples increase in the order, No-P, Mod.-P, Heavy-P, that is, with increasing rate of topdressing and increasing level of inorganic phosphorus (Table 2). This increase of CEC with increasing inorganic-phosphorus content has been previously reported from laboratory experiments (Prince and Toth 1936; Toth 1937; Hester 1937). Mattson (1933) has suggested that the combination of iron and

* 0–2 in. acre = 240,000 lb and 2–5 in. acre = 420,000 lb. Annual losses of P as farm products were assumed to be 5 lb P/acre from the topdressed soils for the period after topdressing was commenced. The loss of P from the No-P soils was assumed to be nil as the sites were unproductive and were seldom grazed, and losses were probably balanced by occasional transfer of fertility by stock from more fertile soils.

aluminium with increasing amounts of phosphate results in an amorphous precipitate in which an increasing number of hydrogen ions derived from the phosphate radical are available for cation exchange. A similar increase in CEC occurs when the anion is humate or silicate.

Base Status and pH (Table 1)

The topdressing of these soils has had no significant effect on soil pH but it has increased the total-exchangeable-base content (TEB) particularly at 0–2 in. and to a lesser extent at 2–5 in. The increase is greater in the Heavy-P than in the Mod.-P soils. At 5–8 in. there is no difference between the soils. The percentage base saturation (% BS) increases with the TEB from No-P to Heavy-P but not quite to the same extent because of the increased CEC. The increased TEB content of the topdressed soils is due solely to an increase in exchangeable calcium. This increase in exchangeable calcium with increasing rate of phosphate topdressing is probably mainly due to the calcium added in the phosphatic fertilisers. Because of lack of response to heavy liming, lime is only applied at low maintenance rates. In yellow-brown loams and related brown granular clays of the Waikato district, Dixon and Taylor (1941) found a similar increase in exchangeable calcium but at the same time a decrease in exchangeable magnesium and potassium which they considered was due to the replacement of these ions by calcium ions. No such decrease is found in the present soils. It may be that the level of exchangeable magnesium and potassium has been maintained by topdressing with potash salts and serpentine superphosphate.

Effect of Phosphate Topdressing on Major Categories of Phosphorus (Table 2)

The total phosphorus contents of the topdressed soils are higher than those of the No-P soils down to five inches, but below this depth the values are similar for all the soils. In each of the topdressed soils the increase has been much greater at 0–2 in. than at 2–5 in. Although the total amount of phosphorus added to the topdressed soils is similar, the increase at 0–2 in. has been much greater for the Heavy-P than for the Mod.-P soils. At 2–5 in. the values are similar. The lower value for the Mod.-P soils at 0–2 in. is due most probably to greater losses of phosphorus in farm products, because of a longer period under intensive farming.

The similarity of the total phosphorus values at 5–8 in. indicates that the added phosphate has not penetrated to this depth. The values from the dilute-acid extractions (Table 3) similarly show no evidence of the added phosphate having penetrated below five inches. In addition, it is possible to account satisfactorily for the added phosphorus in the increase of the total phosphorus content of the 0–5 in. layer plus estimated losses in farm products. The increase of the total phosphorus content at 0–5 in. is equivalent to 470 lb P/acre* for the Heavy-P soils and 400 lb P/acre for the Mod.-P soils. The addition of the estimated losses as farm products brings these figures to 510 lb and 525 lb P/acre respectively. In view of the assumptions made and the rough accuracy

of farm fertiliser practices, these figures approach satisfactorily the estimated figure of 600 lb P/acre for the amount of phosphorus added.

The lack of penetration of the added phosphate, despite the heavy rate of application on the Heavy-P soils and the long period of topdressing on the Mod.-P soils indicates the very large capactiy for phosphate retention of these soils. This lack of penetration has been found by Jackman (1951) in the related yellow-brown pumice soils, although in these latter soils the amount of topdressing (230 lb P/acre as superphosphate) was lower over a shorter period of topdressing (11 years). In contrast, Doak (1933) found much greater penetration in a yellow-grey earth near Marton: phosphorus added at the rate of 40 lb P/acre as superphosphate penetrated to 4–6 in. after four annual dressings.

TABLE 2. EFFECT OF PHOSPHATE TOPDRESSING ON MAJOR CATEGORIES OF SOIL PHOSPHORUS AND ON THE PERCENTAGE IN EACH CATEGORY

Soils	Depth (in.)	mg P/100 g oven-dry soil as:					Percentage of Total P as:			
		Total P.	Org. P	Inorg. P	Fe + Al-P	Ca-P	Org. P	Inorg. P	Fe + Al-P	Ca-P
No-P	0–2	230	139	91	81	10	60	40	35	5
	2–5	221	129	92	75	17	58	42	34	8
	5–8	205	116	89	81	8	57	43	39	4
Mod-P	0–2	323	159	164	136	27	49	51	42	9
	2–5	264	145	119	109	10	55	45	41	4
	5–8	217	124	93	87	6	57	43	40	3
Heavy-P	0–2	370	153	217	179	38	41	59	48	11
	2–5	253	128	125	110	15	51	49	43	6
	5–8	208	104	104	94	10	50	50	45	5

Organic Phosphorus (Table 2)

The organic phosphorus, carbon, and nitrogen values (Table 1) tend to be only slightly greater in the topdressed than in the untopdressed soils, although there has undoubtedly been greater pasture production and return of organic residues on the former soils. It would appear, therefore, that the use of fertilisers, mainly phosphate and potash, has increased biological activity and the rate of mineralisation of organic residues. In a similar comparison of an untopdressed and topdressed sample of a yellow-brown loam that had been under pasture for 22 years, Burgess and Davies (1951) found no difference between the organic phosphorus contents. In contrast, on a yellow-brown pumice soil, Jackman (1951) found large increases in organic phosphorus content after the phosphate topdressing. His comparisons were, however, between soils recently sown to pasture from a scrub vegetation and it is possible that the increase in organic phosphorus content was due primarily to the change in vegetation and not to the phosphate topdressing.

Inorganic Phosphorus (Table 2)

The increased inorganic phosphorus content of the Mod.-P and Heavy-P soils after topdressing is mainly in the form of Fe- and Al-bound phosphorus. There has been a small increase in the level of apatite phosphorus. Because of the high sesquioxide content and the moderately acid reaction of these soils, this build-up of Ca-bound apatite phosphorus is not considered to be due to retention of phosphate by calcium but to residual water-insoluble apatite phosphorus added in phosphatic fertilisers such as basic slag, rock phosphate, and superphosphate.

The accumulation of the added phosphate almost wholly as inorganic phosphorus has considerably changed the relative proportions of inorganic and organic phosphorus in the soils (Table 2). In the No-P soil almost 60% of the total phosphorus is in organic form and there is little change in the proportions with depth. In the topdressed soils, however, the inorganic phosphorus predominates in the 0–2 in. samples but at the lower depths the phosphorus is still mainly organic.

Phosphorus Soluble in Neutral Ammonium Fluoride (Tables 3 and 4)

The amount of phosphorus extracted by the neutral ammonium fluoride from these soils is very high and represents a large proportion of the Fe- and Al-bound phosphorus. The close similarity of the proportion of the Fe- and Al-bound phosphorus extracted from each soil (mean 59.5%) suggests that the amount extracted is limited by the conditions of the extraction rather than by the solubility of the Fe- and Al-bound phosphorus. Four of the soils were subjected to three successive extractions which accounted for between 75% and 90% of the Fe- and Al-bound phosphorus and there was still an appreciable amount of phosphorus in the third extract.

TABLE 3. EFFECT OF PHOSPHATE TOPDRESSING ON THE PHOSPHORUS SOLUBLE IN VARIOUS SOLVENTS

Soils	Depth (in.)	mg P/100 g oven-dry soil extracted by							
		Water	2.5% HAc	Truog Reagent	Lactate Reagent	1% Citric Acid			Neutral NH_4F
						Total P	Inorg. P	Org. P	
No-P	0–2	0.05	0.5	1.2	0.05	11.2	1.4	9.8	48
	2–5	0.03	0.2	—		10.3	3.3	7.0	46
	5–8		0.2	—		7.2	3.3	3.9	43
Mod-P	0–2	0.06	3.3	2.5	0.05	17.5	8.1	9.4	81
	2–5	0.03	1.0	—		13.6	6.4	7.2	64
	5–8		0.2	—		8.3	3.8	4.6	54
Heavy-P	0–2	0.09	7.6	6.1	0.2	20.8	11.0	9.8	110
	2–5	0.04	0.6	—		12.8	5.5	7.3	64
	5–8		0.2	—		7.7	3.1	4.6	53

The very high solubility of the Fe- and Al-bound phosphorus in neutral ammonium fluoride indicates that the phosphorus of this category is predominantly Al-bound (Part I, Saunders 1959) and the increases in the amount extracted from the 0–2-in. samples following topdressing indicate that the added phosphate has been retained mainly by the aluminium of the clay fraction. 60% and 63% respectively of the accumulated Fe- and Al-bound phosphorus in the Mod.-P and Heavy-P soils is recovered by the single ammonium fluoride extraction.

TABLE 4. Percentage of Total Inorganic Phosphorus Extracted by Various Solvents and of Fe + Al-bound P Extracted by Ammonium Fluoride

Soils	Depth (in.)	2.5% HAc	Truog Reagent	Lactate Reagent	1% Citric Acid	Neutral NH_4F
No-P	0–2	0.5	1.2	0.05	1.5	59
	2–5	0.2	—		3.0	61
	5–8	0.2	—		2.9	53
Mod-P	0–2	2.0	1.5	0.03	4.9	60
	2–5	0.8	—		7.6	59
	5–8	0.2	—		3.5	62
Heavy-P	0–2	3.5	2.8	0.1	5.1	61
	2–5	0.5	—		6.9	58
	5–8	0.2	—		3.2	55

Phosphorus Soluble in Dilute Acids (Table 3 and 4)

Phosphate topdressing has appreciably increased the inorganic phosphorus soluble in 1% citric acid and 2.5% acetic acid only in the 0–2 in. layer. At 2–5 in. there has been a slight increase and at 5–8 in. no difference between soils is shown. As these stronger extractants showed no effect of topdressing below two inches, extractions of the lower layers with Truog and Egner reagents were not done. Even at 0–2 in. practically no phosphorus was soluble in Egner's reagent, the weakest of the extractants. The phosphorus extracted from 0–2 in. by the other extractants (citric acid, acetic acid and Truog's reagent) increases in the order No-P, Mod.-P, Heavy-P.

The increase in the amount of phosphorus soluble in the dilute acids is due not only to the increasing amount of inorganic phosphorus from the No-P to Heavy-P soils but also to the increasing solubility of the inorganic phosphorus (Table 4) with increased rate of topdressing.

The citric acid values for these soils are complicated by the extraction of a considerable amount of organic phosphorus which results in very high values for total phosphorus extracted even for the No-P soils. These high values for total phosphorus soluble in citric acid are a characteristic of the yellow-brown loams and are quite out of step with the strong pasture-growth response to added phosphate. However, if the organic phosphorus is subtracted from the total phosphorus

extracted by citric acid the resulting inorganic phosphorus value is very low for the No-P soils and similar to the other dilute acid values. It has been noted above that there is no great difference between the total organic-phosphorus content of these soils and similarly the amount of organic phosphorus extracted by citric acid shows no difference between the three rates of topdressing. The citric acid inorganic phosphorus values are greater than the acetic acid and Truog values except for the 0–2 in. No-P samples. This is no doubt an expression of the longer period of extraction and the greater ability of the citrate ion to form a complex with iron and aluminium of the soil and displace phosphorus, both inorganic and organic. It could be that the large amount of organic phosphorus extracted depresses the amount of inorganic phosphorus in solution and this is a possible explanation for the low inorganic value at 0–2 in. in the No-P soils. In the topdressed soils where the solubility of the inorganic phosphorus is greater this effect does not appear.

Also included in Table 3 are the amounts of phosphorus in 1 : 10 soil : water extracts. The values of the No-P and Mod.-P soils are similar and definitely lower than that of the Heavy-P soils. The values are very low even in the Heavy-P soils. These extractions were made for only 30 min., but from general experience of these soils the short period of extraction is not the major reason for the low values. The low values emphasise the very strong retention of added phosphate which is indicated by the lack of penetration.

The dilute acid extractions serve well to differentiate between the three phosphate treatments and a pot trial was run to determine the relationship between the dilute-acid phosphorus values and the available phosphorus as determined by the dry-matter yield and phosphorus uptake of radishes.

Effect of Phosphate Topdressing on Level of Available Phosphorus (Table 5)

Because there was not sufficient of the original soil samples for a pot trial, new soil samples were collected. Although the same sites were sampled, it was found that the dilute-acid values for three of the sites, one from each level of topdressing, had increased since the original samples were collected because of subsequent topdressing. As the main object of this pot trial was simply to establish the relationship between the dilute-acid values and the relative levels of available phosphorus in the soils, this change in the dilute-acid values did not matter. In fact it resulted in a wider range of dilute-acid values than was obtained originally which was beneficial to the object of the trial. In addition to soils from the six sites already described a seventh sample was collected from a site of low to moderate phosphorus status.

Each soil was treated with three rates of added phosphate—0, 20, and 180 mg P/pot. These are called P_0, P_1, and P_9. The dry-matter yields of the adult leaves and their phosphorus content are set out in Table 5 in order of increasing phosphorus status. The phosphorus status of a soil refers to its ability to meet the phosphorus requirements of plants.

There has been a response to the added phosphate in all but soil No. 7, the degree of response decreasing as the dilute-acid values increase. At the P_1 level of added phosphate the yields are similar for soils Nos. 1 to 6 but still below that for soil No. 7. At P_9, however, the yield for all soils is similar and it is evident that the maximum yield has been attained.

TABLE 5. DRY MATTER YIELDS AND THE PHOSPHORUS UPTAKE OF RADISH LEAVES AND VALUES FOR SOIL PHOSPHORUS
(mg P/100 g oven-dry soil)

Soil No.	Dry Matter Yield, g/pot			P Uptake by Leaves, mg P/pot			Soil P Soluble in	
	P_0	P_1	P_9	P_0	P_1	P_9	Truog	Acetic
1	0.279	1.061	1.890	0.59	2.74	8.46	0.7	0.8
2	0.585	1.207	2.083	1.20	3.22	10.29	1.6	4.2
3	0.705	1.434	2.167	1.45	3.86	9.56	1.8	2.4
4	0.733	1.271	2.078	1.56	3.15	8.66	2.1	2.3
5	0.868	1.282	2.005	1.88	3.32	8.50	4.2	6.2
6	1.050	1.433	1.748	2.96	4.32	8.75	4.7	7.5
7	1.727	1.673	1.868	4.79	5.52	9.70	9.7	14.4

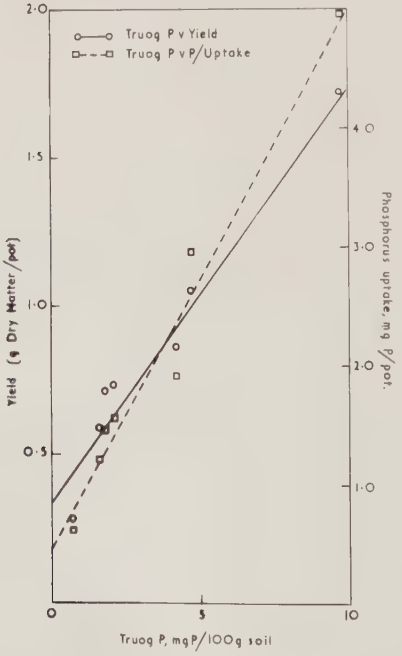

Fig. 1.—Relationship between Truog phosphorus test values and dry-matter yield and phosphorus uptake.

Both the dry-matter yield and the uptake of phosphorus increase with increasing level of phosphorus soluble in Truog reagent and 2.5% acetic acid (Table 5). In Fig. 1 the plant and Truog values have been plotted against each other. The correlation between the plant values and the dilute-acid values for the soils is clearly very good, and the latter may be accepted as giving a good evaluation of the relative phosphorus status. Using these results, the dilute-acid values obtained with Truog's reagent and 2.5% acetic acid have been put into four groups separating the soils into those which give (a) a large response, (b) a medium response, (c) a small response and (d) no response to added phosphate. This grouping is set out in Table 6.

TABLE 6. GROUPING OF DILUTE-ACID PHOSPHORUS VALUES ACCORDING TO RESPONSE TO PHOSPHATE IN POT TRIAL AND BY PASTURE IN THE FIELD

Degree of Response	Pot Trial			Pasture Response Dep. Agric. Test Values
	Truog Values	Converted Truog Values*	Acetic Values	
Large	0–1	0– 2.5	0– 1	0.– 2.5
Medium	2–3	3– 7	2– 5	3– 6.5
Small	4–6	8–15	6–10	7–12.5
None	7–	16–	11–	13–

* Truog values for soils converted into terms of the scale used by the Soil Advisory service of the Department of Agriculture.

The Soil Advisory Service of the Department of Agriculture use the Truog extraction for determining the phosphorus requirements of pasture soils (Davies 1953). They express their results as parts per 50,000,000 parts of extract and the grouping of their scale according to pasture response on the yellow-brown loams in North Taranaki (A. C. Burgess, pers. comm.) is shown in the column headed Pasture Response. (The soil testing by the Department is carried out on samples from 0–3 in. and the values shown in Table 6 are corrected from the 0–3 in. values to apply to 0–2 in.). The Truog values for the soils of the pot trial are expressed in the same scale in the column headed "Converted Truog Values". The agreement between the levels of response in the pot trial and that found in the field is very good. Referring back to the dilute-acid values for the original soil samples (Table 3) it can be seen that: (a) the No-P soils have a low phosphorus status and would respond strongly to phosphate topdressing, (b) the Mod.-P soils although they have been regularly topdressed for many years have only a medium phosphorus status and would be expected to respond well to further phosphate topdressing, (c) the Heavy-P soils have a very high phosphorus status and would be expected to give only a small response to added phosphate.

Effect of Topdressing on "Free" Iron and Aluminium (Table 7)

At 0–2 and 2–5 in. the amount of iron and aluminium extracted by McKenzie's (1954) hydrosulphite treatment decreases in the order No-P, Mod.-P, Heavy-P; that is, with increasing rate of topdressing. At 5–8 in. the interpretation of the results is complicated by a very high value for iron (1.94%) in one of the No-P samples; the other sample has a value of 1.54%, which is similar to the values for the Mod.-P and Heavy-P soils. In view of this and the fact that the aluminium values at 5–8 in. show no tendency to decrease with increasing rate of topdressing, it is reasonable to consider the high Fe value (1.94%) anomalous. In this case neither the iron nor the aluminium values at 5–8 in. show any significant effect of the topdressing.

TABLE 7. EFFECT OF PHOSPHATE TOPDRESSING ON THE AMOUNT OF ALUMINIUM AND IRON EXTRACTED FROM A YELLOW-BROWN LOAM BY 'HYDROSULPHITE' EXTRACTION

Depth (in.)	g Al/100 g oven-dry soil			g Fe/100 g oven-dry soil		
	No-P	Mod-P	Heavy-P	No-P	Mod-P	Heavy-P
0–2	0.94	0.83	0.72	1.57	1.42	1.36
2–5	0.93	0.79	0.79	1.54	1.42	1.26
5–8	0.99	0.93	0.97	1.94*	1.55	1.46
				1.54		

* The individual values from the two No-P soils.

TABLE 8. EFFECT OF WETTING AND DRYING WITH AND WITHOUT ADDED PHOSPHATE ON THE ALUMINIUM AND IRON EXTRACTED BY 'HYDROSULPHITE' EXTRACTION FROM THE NO-P SOILS

Temperature of Treatment	g Al/100 g oven-dry soil		g Fe/100 g oven-dry soil	
	Without P	With P	Without P	With P
40–45°C	0.83	0.79	1.59	1.59
80°C	0.67	0.44	1.30	1.30

An explanation of these results is that the iron and aluminium have become immobilised by reaction with the added phosphate. Prince and Toth (1936) and Toth (1937) have reported a decrease in the amount of iron extracted by Truog and Drosdoff's procedure after the soil had been treated with increasing amounts of phosphate in the laboratory. Aluminium was not determined. A similar laboratory test was carried out using the present No-P soils.

The two No-P (0–2 in.) soils were wet and dried twelve times with and without phosphate. Phosphate added as KH_2PO_4 in solution was

equal to the difference between the mean values for total phosphorus in the No-P and Heavy-P soils (131 mg P %). The soils were dried at two temperatures, 40° and 80°C. After the final drying the soils were left exposed to the air for 14 days. The treatment at 40°C was intended to simulate conditions occurring naturally in the surface inch or two of the soil. The treatment at 80°C which is outside the range of naturally occurring soil temperatures was used to hasten the reaction between the added phosphate and the iron and aluminium. After the 14 days exposed to air temperatures, the soils were extracted according to the hydrosulphite procedure and the amounts of iron and aluminium extracted determined.

The wetting and drying at 40°C without added phosphate had no effect on the level of free iron or aluminium in the two soil (Tables 7 and 8). The treatment at 80°C without phosphate however considerably reduced the amount of iron and aluminium extracted. The addition of phosphate to the soils did not affect the iron values either at 40°C or at 80°C. The aluminium values, however, were decreased by the addition of phosphate. At 40°C the effect was slight but at 80°C it was large. The failure to repeat the results of Prince and Toth and obtain a reduction in free Fe could be due to the nature of the soils, or to a lower concentration of added phosphate in the present experiment.

It appears most probable that added phosphate can immobilise iron and aluminium in soils and decrease the level of free sesquioxides. In the present soils the conversion of the iron, aluminium, and phosphate into difficultly soluble forms, that is, the fixation of the added phosphate has occurred to a greater extent under the heavy rates of topdressing of the Heavy-P soils than under the lower rates used on the Mod.-P soils although the total amount of phosphorus added to both soils is similar.

GENERAL DISCUSSION

The total phosphorus concentration in this soil can be built up to a very high level by phosphate topdressing but at the same time this phosphorus is very strongly retained as shown by the very low concentration (less than 0.1 p.p.m.) in water extracts even for the Heavy-P soils. However, even at the high phosphorus status of the Heavy-P soils the capacity of the soil to retain phosphate is far from being saturated. The high level of available phosphorus has been reached after adding about 3 tons of superphosphate but the total phosphate retention capacity of this soil determined at pH 4 by Piper's method (1950) is equivalent to 110 tons of superphosphate for the 0–5 in. depth (2.7% P). The very large capacity of this soil to retain added phosphate strongly even under high rates of topdressing and under the high rainfall (60 in. per annum) is in accord with the amount and nature of the clay fraction.

The yellow-brown loams as a soil group are characterised by a high colloid content which has been identified as predominantly the amorphous clay mineral allophane with associated amorphous hydrous oxides of aluminium, iron, and silicon (Birrell and Fieldes 1952; Fieldes 1955; Taylor 1932). Because of the difficulty of obtaining complete

dispersion without causing the decomposition of the amorphous clay, the normal mechanical analysis is not possible on these soils. Fieldes (1955) estimates the clay content of the yellow-brown loams as between 40% and 60% and this high clay content alone can be considered as an important factor in the high capacity of the soils to retain phosphate. A simple water dispersion of the present soils yielded 25% of clay.

Feildes (1955) has identified two forms of allophane in New Zealand soils derived from volcanic material which he has called allophane B and allophane A. He has suggested that allophane B is formed first during the weathering of volcanic ash and that it is a mixture of silica and alumina gels which have not yet combined to any extent. The alumina is perhaps protected from combination with the silica by prior combination with organic matter. In allophane A, the silica and alumina have co-precipitated in an open amorphous structure. The clays of many of the yellow-brown loams, including the present soil,* show the characteristics of both forms and are considered a mixture which is called allophane AB. Probably the most important features of these clays, so far as phosphate retention is concerned, are their very small particle size, less than 50 Å, and very high specific-surface area, 400 m^2/g (Birrell and Fieldes 1952). This allows a large proportion of the aluminium to be present at the colloid surface and therefore available to retain phosphate. The extent to which this occurs depends on the pH and the ability of the phosphate ion to replace other anions, such as silicate, humate, and hydroxyl, already in combination with the aluminium.

The decrease in the amount of free iron following topdressing indicates that the hydrous iron oxides are also active in fixing the added phosphate but the large proportion of the Fe- and Al-bound phosphorus soluble in neutral NH_4F indicates that most of the added phosphate has been retained by aluminium.

Because of the large capacity of this soil to retain added phosphate, a very high concentration of phosphate has built up in the 0–2 in. layer. This concentration of the phosphorus in a limited volume of soil is analogous to the crop farming practice of fertiliser placement which brings about a greater utilisation of the added phosphate. It has been shown that the higher the concentration of total phosphorus in this soil the higher is its phosphorus status. However, having the major source of available phosphate in the surface inch of the soil, although a simple and convenient method of placing the fertiliser phosphorus, is a definite disadvantage when the surface soil dries out. Mitchell (1957) has pointed out that pasture growth can be severely retarded when the surface inches of the soil dry out, not because of lack of water, but through lack of available nitrogen, which is concentrated in the surface soil. Although the pasture plants can draw their water requirements from lower depths in the soil, once the soil holding the available nutrients dries out they will cease to grow actively. For the present soil there is practically no available phosphorus below two inches, even

* A differential thermal analysis of a water-dispersed sample of the clay of this soil was done by M. Fieldes.

after very heavy topdressing, and when the roots can no longer absorb phosphate from this depth, plant growth must be retarded.

Available evidence indicates that absorption of phosphate by plant roots occurs from the soil solution (Arnon 1953). The phosphorus status of a soil therefore depends on two factors, the concentration of phosphate in the soil solution, and the ability of the soil to maintain this concentration. These are the intensity and capacity factors discussed by Wiklander (1950). Fig. 2 shows the major sources which can supply phosphate to the soil solution. The very low concentration of phosphate in the soil solution is due to the very strong phosphate retention on the finer soil particles, mainly the clay fraction, the concentration being governed by the equilibrium $P_S \rightleftharpoons P_Y \rightleftharpoons P_E \rightleftharpoons P_F$. Phosphate added to the soil solution is immediately distributed between P_S, P_Y, and P_E, according to the equilibrium. For the present soil, even a considerable increase in the amount of Fe- and Al-bound phosphorus on the clay fraction does not bring about a very high concentration of P_S (Table 3). Therefore, the high phosphorus status in the Heavy-P soils depends on a very rapid replacement of phosphate drawn from the soil solution by the growing plant. The most probable source from which this could occur is the exchangeable phosphorus on the colloid surface, P_E. This form of soil phosphorus is in direct equilibrium with P_S and desorption of P_E can occur very rapidly. A high phosphorus status in this soil evidently depends on a high level of exchangeable phosphorus.

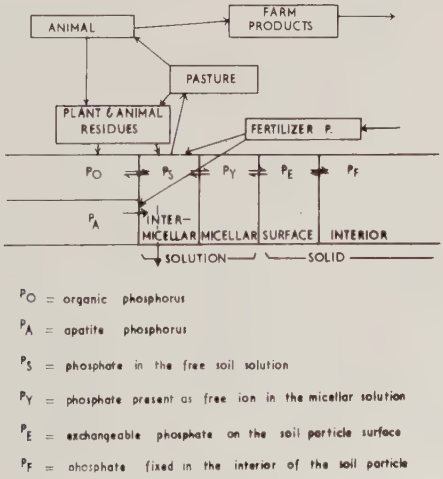

Fig. 2.—Phosphorus in pasture soils.

The level of exchangeable phosphorus is maintained and may be increased by (a) weathering of apatite, (b) decomposition of organic residues, (c) mineralisation of organic phosphorus and (d) application of phosphate fertiliser. The contribution from the apatite in these soils is not easy to evaluate. Cottier (1952) considers that phosphorus in finely ground Nauru rock phosphate is between one third and one half

as available as the phosphorus in superphosphate. There is about 125 to 150 lb P/acre in the 0–5 in. layer of the topdressed soils in the form of apatite and at this level it could make an appreciable contribution to maintaining the level of P_E provided it was not more resistant to weathering than ground Nauru rock phosphate.

The similarity of the levels of organic matter in all of the soils indicates that the soil organic matter is at or near its equilibrium level so that there is virtually complete mineralisation of organic residues. On the topdressed soils, a conservative estimate of the organic residues from leaf production alone would be 8,000 lb dry matter per acre per year and at a P content of 0.4% this amounts to an application of about 30 lb P/acre. The return of phosphorus by the decay of roots would considerably increase this figure. This is a useful addition of phosphorus but it represents the amount added over the whole year and it is most probable that a smaller amount in continuous circulation is involved. The rate of release of this phosphorus is not constant over the year. It must be expected to vary with the biological activity of the soil and with the amount of pasture growth, both of which are largely governed by the soil climate. It would be very useful to know the relationship between the release of this phosphorus and soil climate.

Phosphate topdressing on this soil has been needed, first, to raise the phosphorus status in order to increase pasture production and maintain high-producing pasture species and, second, to balance the losses of available phosphorus that occur by removal in farm products, by fixation and by leaching. In this soil, losses of phosphorus by leaching are negligible. As the level of available phosphorus, which may be represented by the exchangeable phosphorus, P_E, is raised, pasture production is increased up to the point where the soil can meet the phosphorus requirements of the pasture. This increase in uptake of phosphorus by the pasture should be accompanied by a parallel increase up to a maximum in the losses of phosphorus as farm products.

The accumulation of phosphorus as P_E after phosphate topdressing upsets the equilibrium between P_E and P_F, the fixed phosphorus, and fixation of the added phosphorus occurs slowly to restore equilibrium. It has been suggested in a previous section that the decrease in the amount of iron and aluminium extracted by sodium hydrosulphite is due to iron and aluminium being immobilised by the added phosphate and is a measure of the extent of phosphate fixation. This decrease of the amount of extractable iron and aluminium has occurred to a greater extent in the Heavy-P soils than in the Mod.-P soils, indicating that there has been more fixation of phosphate in the soils of higher phosphorus status, that is, the soils of higher level of P_E. The indications are, therefore, that the higher the level of P_E the greater is the amount of the added phosphate that is fixed. This idea is in accord with the generally found field result that for pasture soils a single large topdressing, which would raise P_E to a high level, gives less pasture production than the same amount of phosphate added as several smaller dressings, provided the smaller dressings approximate to an optimum rate (Hudson *et al.* 1933; Dodd 1951). Less than optimum rates of topdressing would not raise P_E to a sufficiently high level for a valid comparison.

On the basis of these ideas, as the phosphorus status of this soil is raised the greater are the losses of available phophorus and the higher the rate of phosphate topdressing required to maintain the phosphorus status. Considering the long period of topdressing on the Mod.-P soils it is probable that they have reached a phosphorus status at which the losses of available phosphorus are balanced by topdressing at 20–30 lb P/acre/year. Continued topdressing at this rate will probably not greatly improve the phosphorus status of these soils. Under heavy phosphate topdressing of 60–80 lb P/acre/year the phosphorus status of this soil has been rapidly raised to a level when little response is expected to additional phosphate but a higher rate than 20–30 lb P/acre will be needed to maintain this level. Considering the speed with which the improvement has been attained, it is probable that 60–80 lb P/acre/year is more than is required simply as a maintenance dressing. Very little of the phosphorus added to the Heavy-P in excess of the maintenance rate is required by the pasture, and the remainder only serves to increase the level of exchangeable phosphorus and then is fixed and becomes unavailable before it can be used by the pasture.

Without good field evidence it should not be assumed that a very high phosphorus status at which little or no phosphate response is obtained is the most desirable for pasture production. It is possible that pasture could be produced more economically, from the phosphate point of view, by maintaining the soil at a lower phosphorus status using small seasonal dressing of phosphate. As an example of the beneficial use of small amounts of phosphate on soils of low phosphorus status, the results from the pot experiment may be quoted (Table 5). The dry matter yield of radish and the amount of phosphorus taken up by the plants differed considerably between the seven soils when no phosphorus was applied, P_0. However, at the first level of added phosphorus, P_1 (20 mg P/150 g soil; equivalent to 1.5 cwt superphosphate/1 in. acre) there is not a great difference between the soils which have Truog values of less than 5. With very little added phosphorus, the soils of lowest phosphorus status, comparable to the No-P soils, have produced almost as much as the soils where phosphorus status is comparable to the Heavy-P soils. Results from a pot experiment using a plant of short growing period like radish, cannot be applied directly to pasture under field conditions where the growing period is longer and other conditions considerably different. However, they do illustrate the effectiveness of a small dressing of phosphate over a short period of time under suitable conditions, even on the soils of low phosphorus status. Questions of this nature can, however, only be answered by field experiment and experience.

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REFERENCES

Arnon, D. I. 1953: *Agronomy 4:* 1-42.
Birrell, K. S.; Fieldes, M. 1952: *J. Soil Sci. 3:* 156-66.

Birrell, K. S.; Gradwell, M. 1956: *J. Soil Sci. 7:* 130-47.
Bray, R. H.; Kurtz, L. T. 1945: *Soil Sci. 59:* 39-45.
Burgess, A. C.; Davies, E. B. 1951: *Proc. N.Z. Grassl. Ass.:* 46-55.
Cottier, K. 1952: *N.Z. J. Agric. 84:* 183-9.
Davies, E. B. 1953: *N.Z. J. Agric. 87:* 306-12.
Dixon, J. K.; Taylor, N. H. 1941: *N.Z. J. Sci. Tech. A24:* 146-51.
Doak, B. W. 1933: *N.Z. J. Sci. Tech. 15:* 155-62.
Dodd, D. R. 1951: *Ohio Fm Home Res. 36:* 88-93.
Dyer, B. 1894: *Trans. chem. Soc. 66:* 115-67.
Egner, H. 1932: *Medd. CentAnst Försökv. Jordba., Stockh.* p. 425.
Fieldes, M. 1955: *N.Z. J. Sci. Tech. B37:* 336-50.
Hester, J. B. 1937: *J. Amer. Soc. Agron. 29:* 10-16.
Hudson, A. W.; Doak, B. W.; McPherson, G. K. 1933: *N.Z. Dep. sci. industr. Res. Bull. 31:* 49-81.
Jackman, R. H. 1951: *Proc. N.Z. Grassl. Ass.:* 176-82.
Kurtz, L. T. 1942: *Industr. Engng. Chem. (Anal.) 14:* 855.
Mackenzie, R. C. 1954: *J. Soil Sci. 5:* 167-72.
Mattson, S. 1931: *Soil Sci. 31:* 311-31.
Metson, A. J. 1956: *N.Z. Soil Bur. Bull. 12.*
Mitchell, K. J. 1957: *Emp. J. exp. Agric. 25:* 69-78.
New Zealand Soil Bureau 1954: *N.Z. Soil Bur. Bull. 5.*
Piper, C. S. 1950: "Soil and Plant Analysis." Univ. Adelaide, pp. 192-5.
Prince, A. L.; Toth, S. J. 1936: *Soil Sci. 42:* 281-90.
Saunders, W. M. H. 1959: *N.Z. J. agric. Res. 2:* 427-444.
Taylor, N. H. 1932: *N.Z. J. Sci. Tech 14:* 338-52.
Toth, S. J. 1937: *Soil Sci. 44:* 299-314.
Truog, E. 1930: *J. Amer. Soc. Agron. 22:* 874-82.
Wiklander, L. 1950: *Ann. R. Agric. Coll. Sweden 17:* 407-24.
Williams, E. G.; Stewart, A. B. 1941: *J. Soc. Chem. Ind. 60:* 291-7
———————1943: *J. agric. Sci. 33:* 179-89.

EXPERIMENTS ON THE CONTROL OF RIPE SPOT ON STURMER APPLES

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Summary

Satisfactory control of ripe spot of apples, a storage disease caused by one or both of the fungi *Gloeosporium perennans* Z. et C. and *G. album* Osterw., was obtained by the use of an orchard spraying programme which included phenyl mercury chloride until about mid-December, and captan for the remainder of the season. Storage of Sturmer apples at 36°–38°F inhibited considerably the development of ripe spot. A lapse of several days between picking and placing in cool store did not affect the amount of this disease in Sturmer fruit picked at normal harvesting date and stored for six months.

Introduction

The biology of the two fungi causing ripe spot of apples in store, *Gloeosporium perennans* Z. et C. and *Gloeosporium album* Osterw., was discussed earlier (Brook 1957). The present paper deals with experiments directed towards a control of the disease. Since ripe spot is an important disease of Sturmer apples in Nelson, all of the work described here has been carried out on trees of the Sturmer variety in the Appleby Research Orchard in that district. In the research orchard the predominant species is *G. perennans,* although *G. album* is also present.

Effect of Fungicides on Ripe Spot

As conidia of both fungi arrive on the surface of the apple while it is on the tree, and perhaps also when it passes over a contaminated grading machine, it is generally conceded that application of a suitable fungicide to fruit when it is still in the orchard should protect apples during their store life. It was sought, therefore, in some of the work to select from available fungicides that most useful for spraying on fruit as it approached maturity on the tree. Equal attention was, however, given to an attempt to eradicate the source of inoculum in the orchard by using sprays. It was assumed that if conidia production at stem cankers could be reduced to a large extent, risk of fruit infection would be minimised. While this approach appeared reasonable enough for *G. perennans,* there was doubt about its value for controlling *G. album* which is more rarely found causing stem cankers on apple.

In the 1955-56 and 1956-57 seasons, when single-tree replicates were generally used, spraying was done from the ground with a hand gun. When a large block of trees was given an overall programme during the 1957-58 season, spray was applied with hand-directed 6-nozzle brooms from a spray cart moving at a constant speed. By both methods trees were sprayed to the point of run-off. In all spraying experiments, standard proprietary formulations of fungicides were used.

Experiment I

During the 1955-56 season, six fungicides were compared as protective sprays on ripening fruit. Each material was used on five single-tree replicates arranged in randomised blocks. To avoid complication, each fungicide was used throughout the season from the green-tip stage. To increase the risk of infection fruit was not picked until 21 June, approximately ten weeks after the date on which the apples would normally have been harvested for long-term storage. One set of replicates received no fungicides at all.

To encourage development of ripe spot after picking, one case of fruit from each tree was held in a shed in Auckland at ambient temperatures. Ripe spot was recorded three months after harvest. Table 1 gives details of treatments, and the amount of infection sustained under each.

TABLE 1. EFFECT OF SEVERAL PROTECTIVE FUNGICIDES ON RIPE SPOT OF STURMER APPLES IN 1955-56

Fungicide	Application Dates, and Concentrations				Fruit Picked 21 June, Examined Mid-September	
	23 Sep. (Green tip)	7 Oct. (Late pink); 31 Oct. (Petal fall); (12 Nov. (Closed calyx)	1 Dec.; 22 Dec.; 13 Jan.	3 Feb.; 23 Feb.; 15 Mar.; 3 Apr.; 30 Apr.; 24 May; 15 June	Percentage Apples with Ripe Spot	Mean No. of Spots per Infected Apple
Captan	0.15%	0.15%	0.10%	0.10%	75	4
Ziram	0.27%	0.27%	0.18%	0.18%	91	6
Zineb	0.20%	0.20%	0.13%	0.13%	95	8
Bordeaux*	10/8/100	6/8/100	2/6/100	1/4/100	97	8
Thiram	0.16%	0.16%	0.12%	0.12%	100	11
Dichlone	0.05%	0.05%	0.05%	0.05%	100	12
No fungicide					100	13

* Concentrations of Bordeaux mixture are given as copper sulphate lb/hydrated lime lb/water gal.

While it was clear that the conditions of the experiment were too severe for any of the fungicides used, it also appeared that captan was the most promising material for further trial.

Experiment II

During the season of 1956-57 the effect of eradicant fungicides on spore production from stem cankers was examined. Since the fungi undergo an active period in spring, and since strong chemicals can usually be applied with some degree of safety until the green-tip stage, the experiment was arranged to compare four chemicals at three tree-growth stages, viz, dormant (very early spring), bud movement, and

TABLE 2. EFFECT ON RIPE SPOT OF STURMER APPLES OF ERADICANT FUNGICIDES APPLIED EARLY IN THE 1956-57 SEASON

Application Dates, and Fungicides Used					Fruit Picked 8 Apr., Examined 12 Aug.	
20 Aug. (Dormant)	15 Sep. (Bud movement)	25 Sep. (Green tip)	5 Oct.-15 Jan. (7 sprays)	30 Jan.; 8 Feb.; 28 Feb.; 13 Mar.; 1 Apr.	Percentage Apples with Ripe Spot	Mean Angle
PMC* 0.3%	Nil	Nil	Colloidal sulphur 0.07%	Nil	4.7	12.2
PMC 0.3%	PMC 0.004%	PMC 0.004%	,,	Nil	6.4	14.4
Nil	PMC 0.004%	PMC 0.004%	,,	Nil	14.6	22.4
‡Sod. pent. 1.0%	Nil	Nil	,,	Nil	8.9	16.9
Sod. pent. 1.0%	Lime sulphur† 10.0%	Lime sulphur 3.3%	,,	Nil	14.2	21.7
Nil	Lime sulphur 10.0%	Lime sulphur 3.3%	,,	Nil	14.9	22.0
Lime sulphur 15.0%	Nil	Nil	,,	Nil	8.9	17.3
Lime sulphur 15.0%	Lime sulphur 10.0%	Lime sulphur 3.3%	,,	Nil	20.1	27.1
Dichlone 0.10%	Nil	Nil	,,	Nil	14.6	22.2
Dichlone 0.10%	Dichlone 0.05%	Dichlone 0.05%	,,	Nil	19.3	25.9
Nil	Dichlone 0.05%	Dichlone 0.05%	,,	Nil	12.5	20.6
Nil	Nil	Nil	,,	Captan 0.10%	8.7	15.8
Nil	Nil	Nil	,,	Nil	14.4	22.2
					P0.05 :	6.8
					P0.01 :	9.1

* Phenyl mercury chloride.

† Total concentration of lime sulphur is given. Of this amount 15% is polysulphides.

‡ Sodium pentachlorophenate.

green tip. It was felt that the effect of a single fungicide application at the dormant stage might too readily be masked by inoculation from adjacent trees. Randomised single-tree replicates were not, therefore, used in this experiment. Diagramatically, the layout was as follows:

a	A	A	a
a	A	A	a
α	α	α	α
b	B	B	b
b	B	B	b
β	β	β	β
etc.			

where A, B etc. had dormant applications only, and were buffered by a, b etc. having dormant plus spring applications, and by α, β etc. having spring applications. Sufficient trees for only one quartet under each treatment were available. In general, each fungicide was tested both at dormant and at the two spring stages, but as sodium pentachlorophenate could not be used on trees at bud movement or green tip, lime sulphur was used as a substitute in spring applications.

To give some protection against black spot, seven applications of colloidal sulphur were made to all trees from the open cluster-pink stage until mid January. For comparison with eradicant treatments, four trees received no eradicant fungicides but were sprayed with captan five times from the end of January until harvest. Four trees had no fungicides other than sulphur.

On 8 April, when the fruit was at the stage normally picked for storage, one sample case of apples from each tree was picked, wrapped, and packed in the orchard to avoid the possibility of contamination from the fruit grader. The cases were held in a shed in Auckland at ambient temperatures, and fruit was examined on 12 August, eighteen weeks after harvesting. Table 2 gives details of treatments and their results.

The fact that one application of a heavy concentration of phenyl mercury chloride at the dormant stage reduced ripe spot in stored fruit nearly twelve months later would suggest that this fungicide had acted by reducing the amount of inoculum.

In this experiment, of 269 sporing lesions on fruit all were caused by *G. perennans*. Since, however, this is the predominant species in the research orchard it cannot be inferred that eradicant sprays would give complete protection from *G. album*.

Experiment III

Concurrent with the eradication experiment in 1956-57, an experiment was laid down to test the effect of combining spring eradicant with summer protective fungicides. Phenyl mercury chloride (PMC) was chosen for spring applications, and captan for summer sprays. PMC was used over the period from green tip until mid December, with the addition in one treatment of a heavy dose at the dormant stage. (In New Zealand, PMC may not be used later than December, to prevent the possibility of residue on fruit.) From January until harvest, spraying was with captan. In order to avoid an epiphytotic of black spot on

trees which had no PMC during the first part of the season, those trees were sprayed with colloidal sulphur, a fungicide which is neither a strong eradicant nor a specific for ripe spot. Each treatment was applied to five single-tree replicates in randomised blocks.

As in Experiment II, on 8 April, the normal picking date, one sample case of fruit from each tree was wrapped and packed in the orchard. A second case from each tree was similarly taken on 2 July, twelve weeks later. Both series of samples were held in Auckland at ambient temperatures. Fruit from the first picking was examined on 19 August, nineteen weeks from harvesting, and from the second picking, on 30 September, thirteen weeks from harvesting. In Table 3 details of treatments and their results are shown.

From these results it is clear that neither the early-season PMC sprays nor the summer captan sprays following sulphurs could, by themselves, approach the effectiveness of early PMC followed by summer captan. Addition of a heavy PMC application at the dormant stage increased control of ripe spot to some extent. Of 97 sporing lesions on fruit of the first picking, only 6 were caused by *G. album*, the remaining 91, together with all of 103 from the second picking, being caused by *G. perennans*.

Experiment IV

To check the findings of Experiment III, in 1957-58 a complete block of twenty-five trees was sprayed with PMC from green tip until early December, and with captan from mid December until harvest. Five trees adjacent to the block received no fungicides at all.

On 21 April, at normal picking maturity, twenty cases were packed in the orchard from fruit mixed from all sprayed trees, and ten cases from the unsprayed trees. Ten cases of sprayed, and five of unsprayed, apples were held in Auckland at ambient temperatures and examined on 5 September, nineteen and one-half weeks after harvest. The remaining ten cases of sprayed and five of unsprayed fruit were placed in cool store at 36°–38°F on the day following harvest. (Cool store samples are discussed below under Experiment VI.)

Table 4 gives spraying dates and amounts of ripe spot.

Results of this experiment confirm the earlier findings that a satisfactory spraying programme combines spring and early summer applications of PMC with late summer protective sprays of captan.

EFFECT OF SOME FACTORS OTHER THAN SPRAYING ON RIPE SPOT

Experiment V

To test the assumption that the longer apples remain on the tree, the greater is their chance of becoming inoculated by conidia produced in the autumn flush of sporulation, and in consequence the greater will be the amount of ripe spot in store, an experiment was made on apples of the 1956-57 crop to find the effect of picking time on the incidence of ripe spot. As trees which had received no fungicides through the season were not available, fruit was taken from the block used for Experiment II.

TABLE 3. A COMPARISON OF SPRING AND SUMMER SPRAY PROGRAMMES AGAINST RIPE SPOT OF STURMER APPLES IN 1956–57

Application Dates, and Fungicides Used				Results of Treatments			
				Fruit Picked 8 Apr., Examined 19 Aug.		Fruit Picked 2 July, Examined 30 Sept.	
20 Aug. (Dormant)	25 Sep. (Green tip)	8 Oct. (Open cluster-pink); 26 Oct. (Petal fall); 14 Nov.; (Closed calyx); 29 Nov.; 18 Dec.	9 Jan.; 30 Jan.; 18 Feb.; 13 Mar.; 1 Apr.; 18 Apr.; 6 May; 24 May; 12 June	Apples with Ripe Spot, %	Mean Angle	Apples with Ripe Spot, %	Mean Angle
PMC* 0.3%	PMC 0.004%	PMC 0.004%	Captan 0.1%	1.2	4.8	1.6	6.5
No spray	PMC 0.004%	PMC 0.004%	Captan 0.1%	3.7	10.8	6.9	14.9
No spray	PMC 0.004%	PMC 0.004%	No spray	19.9	26.1	53.0	46.4
No spray	Colloidal sulphur 0.16%	Colloidal sulphur 0.14%	Captan 0.1%	14.2	21.7	29.3	32.7
No spray	Colloidal sulphur 0.16%	Colloidal sulphur 0.14%	No spray	24.7	29.2	71.1	58.0
			P0.05:		6.3		5.7
			P0.01:		8.6		7.8

* Phenyl mercury chloride.

TABLE 4. EFFECT OF SPRAYING WITH PHENYL MERCURY CHLORIDE IN SPRING, AND WITH CAPTAN DURING SUMMER, 1957-58

Application Dates, and Fungicides Used				Results of Treatments			
				Fruit Picked 21 Apr., Held at Ambient Temperatures, and Examined 5 Sep.		Fruit Picked 21 Apr., held at 36°–38°F, and Examined 29 Oct., 8 days out of cool store	
23 Sep. (Green tip); 3 Oct. (Pink); 24 Oct. (Petal fall); 5 Nov. (Closed calyx); 21 Nov.	5 Dec.	18 Dec.	9 Jan.; 28 Jan.; 13 Feb.; 7 Mar.; 28 Mar.	No. of Apples Examined	Apples with Ripe Spot, %	No. of Apples Examined	Apples with Ripe Spot, %
PMC* 0.004%	PMC 0.002%	Captan 0.05%	Captan 0.10%	1288	1.55	1240	0.08
No spray	No spray	No spray	No spray	861	22.53	844	2.72

* Phenyl mercury chloride.

Six pickings were made at intervals of approximately two weeks, beginning one month before the normal harvesting date. At each picking, twenty apples per tree were taken from trees under all the treatments except summer captan and were mixed to pack out four cases. The cases were put immediately into cool store at 36°–38°F. Harvesting covered the period from 13 March to 24 May. On 23 April a few pinpoint lenticel spots were seen on some fruit in the block, and by 24 May the amount of lenticel spot varied from one or two fruits per tree to about half of the fruit per tree affected. Since lenticel spots are often sites for ripe-spot development, and on this account apples with lenticel spots are not in practice accepted for cool storage, at each picking only unblemished fruit was packed.

Of the four cases taken at each date, one was removed from cool store in mid August, one in mid September, one early in October, and the last in mid November. After removal from store, cases were left unopened for a period of from seven to nine days to represent the time required for the fruit to reach a purchaser, and the apples were then examined. Table 5 sets out the data of this experiment.

TABLE 5. Effect of Harvesting Date on the Amount of Ripe Spot in Sturmer Apples held in Cool Storage at 36°–38°F

		Percentage Apples with Ripe Spot in Single-case Samples Removed from Cool Store on:			
		13 Aug.	16 Sep.	7 Oct.	18 Nov.
Harvest dates	13 Mar.	0	0	0	1.1
	26 Mar.	0	0	0	0
	8 Apr.*	0.6	0	0	1.7
	23 Apr.	0	0.6	0	1.7
	7 May	0	0	1.1	5.6
	24 May	0	0	1.2	4.3

* Normal picking date.

It can be seen at once that little ripe spot developed. However, apples from the fifth and sixth pickings had by November developed more infection than those from the earlier harvesting dates. Statistical analysis of the data was not possible, but there is an indication that delaying harvesting increases the incidence of the disease.

The most interesting point arising from this experiment was that while only 1.7% of fruit picked on 8 April and put at once into cool store had developed ripe spot, 4.7% to 20.1% of apples from the same trees picked on the same day and held at ambient temperatures had

become infected (as is shown in Table 2). Cool storage had, it appears, prevented a considerable proportion of ripe spot from developing.

Experiment VI

This suppression of ripe spot development by cool storage was tested in 1957-58, as an adjunct to Experiment IV, by putting samples from sprayed and from unsprayed trees into cool store. Details are given under Experiment IV.

The fifteen cases were removed on 21 October, after twenty-six weeks in store, and fruit was examined eight days later. Results, shown in Table 4, are further evidence that cool storage does by itself give an important practical control of ripe spot. The results also show, however, that fruit with a high ripe-spot potential, the unsprayed apples in this instance, still develop a greater amount of the disease in cool store than fruit with a low ripe-spot potential.

Experiment VII

It was thought that lengthening the delay between harvesting and placing fruit in cool storage might increase the amount of ripe spot in store, and in 1957-58 the following experiment was carried out.

On 17 April 1958, at normal picking time, twenty-one cases were packed from mixed fruit taken from a block of trees and run over the grader. The trees had received the following fungicides:—Bordeaux mixture, 10/8/100 at green tip; lime sulphur, 0.5% + colloidal sulphur, 0.08% at open cluster-pink; PMC, 0.004% at petal fall; captan, 0.075% at closed calyx: thiram, 0.12% on 19 November; captan, 0.05% on 4 December, 18 December, 17 January, and 7 February. Five cases were held in Auckland at ambient temperatures for twenty weeks and were examined on 5 September. Of the remaining sixteen cases, two were placed in cool store at 36°–38°F on 17 April, the day of harvesting, and two on each of the following days until 24 April. Of each pair, one case was removed from cool storage on 21 August, eighteen weeks from harvest, and the second on 21 October, about twenty-six and one-half weeks from harvest. After removal from store, apples were held for eight days before being examined.

In addition to the above, on 5 May 1958, about two weeks after normal picking time, ten cases were packed from trees which had received the same fungicide programme except for the omission of captan sprays in January and February. Two cases were held in Auckland at ambient temperatures for sixteen and one-half weeks, to be examined on 29 August. Two cases were placed in cool store at 36°–38°F on the day of picking, and two on each of the three following days. One case from each pair was removed and examined at the same times as were cases from the other series. Tables 6 and 7 give details of the amounts of ripe spot suffered.

Since nothing approaching the potential amount of ripe spot, as obtained in samples stored at ambient temperatures, developed in any of the cool storage samples, and since there was no increase in ripe spot

TABLE 6. Effect of Delay between Harvesting and Storing on Amount of Ripe Spot Developing in Cool Storage at 36°–38°F on Sturmer Apples from Trees Sprayed until February and Harvested on 17 April

No. of Days between Harvest and Storing	Percentage Apples with Ripe Spot in Fruit Removed from Cool Store on:	
	21 August	21 October
0	0	0
1	0	0.7
2	0	0
3	0	0.7
4	0	0
5	0	0
6	0	1.1
7	0	0.6

Percentage apples with ripe spot in fruit stored at ambient temperatures and examined 5 September: 9.2.

TABLE 7. Effect of Delay between Harvesting and Storing on the Amount of Ripe Spot Developing in Cool Storage at 36°–38°F on Sturmer Apples from Trees Receiving No Fungicides after mid December and Harvested on 5 May

No. of Days between Harvest and Storing	Percentage Apples with Ripe Spot in Fruit Removed from Cool Store on:	
	21 August	21 October
0	0	0
1	0	1.6
2	0.7	0
3	0	1.8

Percentage apples with ripe spot in fruit stored at ambient temperatures and examined 29 August: 28.1.

corresponding with the increase in delay between picking of fruit and its entering cool storage, it would seem that delays of up to seven days at normal picking time or up to three days with slightly more mature fruit did not effect the amount of ripe spot in apples stored at 36°–38°F for twenty-six weeks.

Discussion

From the foregoing re-examination of the spraying factors, and of some aspects of the effect of cool storage on development of ripe spot, it is believed that a basis for a practical control of the disease can be outlined.

Use of an eradicant fungicide, such as phenyl mercury chloride, in the early part of the season is justified, both in theory and in practice, for its effect in reducing the spore inoculum from stem cankers on apple trees. This part of the spray programme is directed more particularly against *Glocosporium perennans*. It has been shown that a schedule of regular protective applications of captan through the latter part of the season is a required sequel to the early eradicant programme. This summer programme is necessary apparently for two reasons. Complete eradication of the fungus in stem cankers is not possible, and protection must be given to fruit from infection by such conidia as escape. The second reason is provided by the work of von Arx (1958), who has shown that *G. album* has a wide host range. Presumably, therefore, an inoculum of conidia of this species can be built up on other hosts from which the spores will reach apples throughout the summer.

With regard to storage, it is general practice to store apples at the lowest suitable temperature, and it has been shown above that cool storage alone will prevent a large part of the potential amount of ripe spot from developing. The present work also confirmed the finding of Taylor and Brien (1943) that the later the apples are picked, the greater will be the amount of ripe spot developing on them. The normal picking dates of apple varieties in New Zealand are usually selected on grounds other than those concerning ripe spot. Determination of picking maturity of apples intended for cool storage is based on their liability to physiological disorders during storage rather than to their possible susceptibility to rots caused by fungi. However, it appears that requirements of picking maturity to give satisfactory freedom from ripe spot are met equally well, and changes are not justified.

Edney (1956) has shown that an apple detached from the tree and inoculated with *G. perennans* is rotted fairly quickly, whereas in an apple inoculated at about the same time but left on the tree infection does not develop. It would seem, therefore, that the delay between harvesting fruit and placing it in cool storage should be as short as possible. However, from the results of Experiment VII above it appears that at normal picking time a lapse of up to seven days may not increase subsequent amounts of ripe spot in store.

In conclusion, what governs the amount of ripe spot in cool store is largely the success, or otherwise, of the control of the fungi in the orchard.

Acknowledgement

Statistical analysis of results was done by Dr. H. R. Thompson of Applied Mathematics Laboratory.

References

von Arx, J. A. 1958: Die "Gloeosporien" des Kernobstes. *Phytopath. Z. 33:* 108-14.

Brook, P. J. 1957: Ripe Spot of Apples in New Zealand. *N.Z. J. Sci. Tech. A38:* 735-41.

Edney, K. L. 1956: The Rotting of Apples by *Gloeosporium perennans* Zeller et Childs. *Ann. appl. Biol. 44:* 113-28.

Taylor, G. G.; Brien, R. M. 1943: Ripe-Spot of Apples (*Neofabraea malicorticis*). *N.Z. J. Sci. Tech. A25:* 63-72.

EFFECT ON HONEY BEES OF ROGOR AND ENDOTHION APPLIED FROM THE AIR AS SPRAYS TO BRASSICAS; TRIAL OF M.G.K. REPELLENT 874

By T. Palmer-Jones,* I. W. Forster,† and G. L. Jeffery†

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Summary

Sixteen fluid ounces of Rogor 40 (40% w/v of active ingredient) was applied from the air in 7 gallons of water per acre to 2 acres of a 32-acre flowering crop of turnips.

An aqueous solution of Endothion containing 0.33% of active material was applied from the air in 30 gallons of water per acre to 2 acres of a 24-acre flowering crop of rape.

Eight ounces of a 50% emulsifiable concentration of M.G.K. repellent 874 was mixed into the Rogor solution and applied with it to the 2 acres of crop.

Both crops were sprayed before bees from nearby apiaries commenced to visit them. Bees collected nectar and pollen extensively from the crops which were of maximum attractiveness.

No repellency was exhibited by the Rogor-M.G.K. repellent 874 mixture or by the Endothion.

Rogor proved highly toxic to field bees, although brood was not affected. It should on no account be applied to flowering crops.

Endothion caused no bee mortality and is safe to apply to flowering brassica crops.

Introduction

Palmer-Jones *et al.* (1959) have described experiments conducted with the aim of finding agricultural chemicals which would control aphids on brassica crops without harming honey bees. The trials of two systemics now described are a continuation of this work.

Systemics are usually very efficient aphicides but, as shown by Palmer-Jones *et al.* (1957), may reach the nectaries of brassicas and cause serious bee mortality. Accordingly it is not safe to recommend the use of a systemic on a flowering crop until its effect on honey bees has been thoroughly studied.

Rogor and Endothion, the systemics tested, were both recently developed and appeared promising for aphid control on brassicas.

Rogor is described as a contact-systemic insecticide of low mammalian toxicity, with the added properties of rapid penetration and a quick breakdown of residues in the plant. It is 0,0-dimethyl S(N-methylcarboxamidomethyl) phosphorothiolothionate. It is claimed to give excellent control of aphids and spider mites on many plants. The extent of potential risks of Rogor to beneficial insects and pollinators is not

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yet known. It is advised that to avoid injury to bees Rogor should not be sprayed on flowering crops or weeds (Fisons Pest Control Ltd. 1958; Fisons Pest Control Ltd. Pamphlet).

Endothion, or 0:0-dimethyl-3,2(5-methoxy-4-pyronyl) methyl phosphorothiolate, has been found effective against a wide variety of insects including aphids. It is considered to be rather less hazardous to use than demeton methyl. It has been shown that Endothion can be used practically without risk to bees. It is inadvisable to reduce the volume of application below 30 gallons per acre which should contain approximately 0.33% of active agent (May and Baker Ltd. 1958).

If a satisfactory bee repellent were available it could be mixed with agricultural chemicals dangerous to bees and applied with them to flowering crops. In this way it would be possible to use such agricultural chemicals without causing bee mortality. A recently developed bee repellent was mixed with Rogor and its efficacy tested. The only information available regarding the repellent was supplied by Messrs Ivory Spray Chemicals Ltd., Nelson, who quoted a letter received from Messrs. McLaughlin, Gormley King Co., Minneapolis, U.S.A. "M.G.K. repellent 874 will repel bees when added to orchard sprays or other crops sprayed with poisonous insecticides like parathion. The material is oil soluble and it is recommended to be used at the rate of about 0.1% by weight for repelling bees."

Experimental

Areas

Rogor was applied from the air to 2 acres of a 32-acre seed crop of York Globe turnips (*Brassica rapa*) about 10 miles north of Oamaru on the Waitaki plains. Nineteen medium-strength hives of bees were established about three-quarters of a mile from the crop.

Endothion was applied from the air to 2 acres of a 24-acre seed crop of rape (*Brassica napus*) two miles north of the other crop. Twenty-five medium-strength hives of bees were established about 100 yd from the crop.

Both seed crops, typical for the district, were the main source of nectar and pollen for bees from the experimental hives, which were the only ones within effective bee range. The crops, growing on very stony silt loam, were in full flower when sprayed.

Application of Sprays

Rogor 40. Sixteen fluid ounces of Rogor 40 (40% w/v of active ingredient with solvent and wetting agent) was applied from the air in 7 gal water per acre to 2 acres of the crop. Application finished by 6.15 a.m. on 22 October, the crop being dry and weather conditions perfect. No bees were on the crop at the time of spraying.

M.G.K. Repellent 874. Eight ounces of a 50% emulsifiable concentration of the repellent was added to the solution of Rogor (0.2% w/v) and applied with it to two acres of the crop (4 oz per acre).

Endothion. Thirty gallons per acre of aqueous solution containing 0.33% of active material was applied to 2 acres of the crop from a plane (calibrated to deliver 7 gal per acre) which made successive runs over the crop. Application finished by 6.30 a.m. on 28 October under perfect conditions. The crop was dry when the Endothion was applied but was thoroughly wetted by the spray. It was dry again by 9 a.m. No bees were on the crop at the time of spraying.

Counts of Field Bees

Counts of field bees were made, as described by Palmer-Jones *et al.* (1959), in the sprayed and unsprayed areas of both crops.

RESULTS

Counts of Field Bees

Crop Treated with Rogor. Conditions favoured bee activity on the morning of application (22nd) as shown by bee counts (Fig. 1). Counts dropped rapidly after noon until 3.30 p.m. when no bees were on sprayed or unsprayed areas of the crop. Although weather conditions at this time were not so favourable as in the morning, fairly high counts should have been obtained. Gale force winds prevented bee flight on the 23rd. On the 24th there was slight activity in the morning only. On the 25th (afternoon) and 26th, weather conditions favoured maximum bee activity.

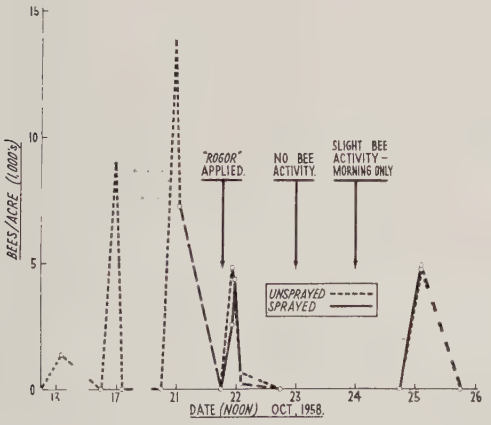

Fig. 1

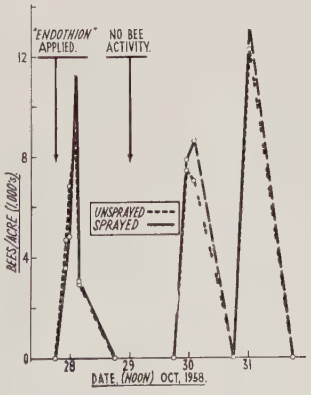

Fig. 2

Fig. 1.—Hive bees per acre on crop treated with Rogor plus repellent.

Fig. 2.—Hive bees per acre on crop treated with Endothion.

Crop Treated with Endothion. On the day this was applied (28th) conditions favoured bee activity (Fig. 2). On the 29th a trace of rain fell and bees did not fly. The 30th and 31st were suitable for bee activity.

Effect of Insecticides upon Field Bees

The toxic action of the insecticides was studied by picking field bees off the crops and placing them in cages provided with feeders holding sugar syrup. These cages were kept under observation in an empty storey above a hive.

Rogor. On the day this was applied, 36 bees were collected in the morning; all were dead within 24 hours. At noon on the day of application all the hives in the experimental apiary were excited and a few bees in front of most were showing symptoms of poisoning. Dead bees in small numbers were being carried out of all hives by 2.30 p.m. Corner hives, which usually have most field bees, were more severely affected than others; bees round their entrances were excited and showed symptoms resembling those of demeton methyl poisoning. Dead bees were brought out of the hives together with ones showing symptoms of a nerve poison. On the 23rd there was no bee activity because of adverse weather but several hundred dead bees had been carried out of the hives. On the 24th, bee flight was possible only in the morning and slight mortality in field bees from the more active hives was noticeable in the afternoon. Bees were active on the afternoon of the 25th and all day on the 26th, but there was no further mortality.

Endothion. On the day of application, 80 bees were collected in the morning and 39 in the afternoon. These and 25 bees collected on the afternoon of the 30th showed no undue mortality when held for 48 hr.

Bumble Bees

All bumble bees observed on the crops were *B. terrestris.*

Bumble bees were counted on the crops in the same way as honey bees.

In the field sprayed with Rogor the maximum count was 169 bumble bees per acre and in the field sprayed with Endothion the maximum was 97 per acre.

There was no evidence that either insecticide caused bumble bee mortality or repelled them.

Behaviour of Honey Bees on Crops, and Repellency

Bees collected nectar and pollen extensively from both crops after the sprays had been applied. Although the crops smelt strongly after spraying, bees visited the flowers normally.

There was no evidence (Figs. 1, 2) that Rogor plus the repellent or Endothion exerted bee repellency.

Effect of Insecticides upon Colonies

Rogor was highly toxic but only to field bees. Endothion caused no bee mortality. No adverse effect on brood in either experimental apiary was observed during the course of the experiment or later.

Protection of Observers Against Insecticides

Rogor has a strong smell but is far less unpleasant to handle than demeton methyl. Face masks were worn on the morning of application when counting bees in the portion of the crop sprayed with Rogor; they were dispensed with in the afternoon without any ill effects.

Face masks were not worn when counting bees soon after the crop had been sprayed with Endothion: no ill effects were experienced.

DISCUSSION

Bee counts on the crop sprayed with Rogor reached over 4000 per acre on the morning it was applied, but dropped to zero in the afternoon. This cessation of activity was not due to the Rogor having affected all the field bees as most were still alive and survived the experiment. It was caused by the hives becoming so disorganised that bees ceased visiting the crop. Later they returned to it and suffered further mortality which continued for 2 days after spraying.

Rogor is closely related chemically to demeton methyl and the symptoms of bees poisoned with it resembled those of ones poisoned with demeton methyl. As in the case of demeton methyl poisoning it had no effect on brood.

Although only 2 acres of the crop were sprayed with Rogor the apiary suffered severe losses of field bees. If Rogor had been applied to a slightly larger area it would have almost certainly killed all the field bees.

There was no evidence that M.G.K. repellent 874 exerted repellency when applied mixed with Rogor.

No repellency was exerted by Endothion; it caused no bee mortality although applied at a time when the area sprayed was very attractive to bees.

It was apparent that the Endothion spray did not have much effect upon the aphids (*Brevicoryne brassicae* (L)) infesting the crop. Messrs May and Baker (Dagenham, Essex, England) have advised us in a personal letter that *Brevicoryne brassicae* L. is quite readily killed in Britain by 0.02% to 0.04% of Endothion applied at 100 gal per acre on the ground. In our experiment 0.33% of Endothion was applied from the air at 30 gal per acre; the crop was thoroughly saturated by the spray and must have absorbed it. The ineffectiveness of the Endothion against the aphids is therefore puzzling and specialists in the field of aphid control should investigate its action against aphids when applied under New Zealand conditions.

CONCLUSIONS

Rogor should on no account be applied to flowering brassica crops.

M.G.K. repellent 874 exerted no repellency when applied to a turnip crop in the manner described in this paper.

Endothion can be applied in safety to flowering brassica crops,

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References

Fisons Pest Control Ltd., Chesterford Park Research Station, near Saffron Walden, England. 1958: *Rogor 40.*

Fisons Pest Control Ltd. *Pamphlet (undated).*

May and Baker Ltd., Dagenham, Essex, England, 1958: *Preliminary Data Sheet Endothion.*

Palmer-Jones, T.; Forster, I. W.; Griffin, L. A. M. 1957: Effect on Honey Bees of Metasystox Applied from the Air as a Spray to Chou Moellier. *N.Z. J. Sci. Tech. A38:* 752-69.

Palmer-Jones, T.; Forster, I. W.; Jeffery, G. L. 1959: Effect on Honey Bees of DDT and Thiodan applied from the Air as Sprays to Chou Moellier. *N.Z. J. agric. Res. 2:* 481-7.

EFFECT ON HONEY BEES OF DDT AND THIODAN APPLIED FROM THE AIR AS SPRAYS TO CHOU MOELLIER*

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(*Received for publication, 23 January 1959*)

Summary

A five-and-a-half acre crop of flowering chou moellier was sprayed from the air with a DDT emulsion at the rate of 2 lb of 100% p.p.i. DDT in 7 gal water per acre.

1.2 lb of 100% thiodan in 7 gal water was applied from the air to one acre of a 25-acre flowering chou moellier crop.

Both sprays were applied before bees from nearby apiaries commenced to visit the crops. Bees collected nectar and pollen extensively from the crops which were of maximum attractiveness.

Honey bees were repelled by the DDT for 6 days after application, but there was no evidence that it repelled bumble bees. Some mortality occurred in field bees, but it was not very high and hives were not weakened and brood was not affected.

It is considered that DDT emulsion, if applied before bees visit a flowering brassica crop, will cause only slight mortality. It should be valuable for use when a crop must be sprayed to save it from destruction by pests.

Thiodan exerted no repellency and was more lethal to field bees than the DDT. Although no adverse effect on adult bees or brood was observed in the apiary it is considered that the hives would have been seriously affected if an area of more than one acre had been sprayed.

Thiodan should not be applied to flowering brassica crops.

Introduction

Brassica crops grown for seed often become heavily infested during the spring flowering period with aphids which may cause serious damage. The crops are particularly attractive to honey bees at this time as other sources of nectar and pollen are scarce. Honey bees are essential for pollination of brassica crops and the Apiaries Protection Regulations 1957 prohibit the application of agricultural chemicals toxic to bees to cruciferous crops during the period when they are attractive to bees. The problem, therefore, is to find agricultural chemicals which will kill aphids on the crops without harming bees.

The effect on honey bees of DDT and thiodan when applied to brassica crops in flower was studied in the following experiment in the hope of solving this problem. In such experiments the effect of the agricultural chemicals upon aphids is tested by the Department of Scientific and Industrial Research.

* Chou moellier = marrow-stem kale (*Brassica oleracea* L.)

† Animal Research Station, Department of Agriculture, Wallaceville.

‡ Horticulture Division, Department of Agriculture, Oamaru.

DDT was chosen because it had been shown previously by Palmer-Jones *et al.* (1954) and Palmer-Jones and Forster (1958) that it could be applied on both clover pasture and lucerne in flower without danger to bees.

Thiodan is a sulphur-containing heterocyclic hydrocarbon compound (1,2,3,4, 7,7-hexachlor-bicyclo-(2,2,1)-hepten-5,6-bisoxymethylene sulphite). Palmer-Jones (1958; 1959) tested its effect on honey bees in the laboratory and also when applied at maximum rates to a crop of flowering broad beans in a cage. No bee mortality occurred in the cage experiment and thiodan appeared promising for the control of aphids on brassicas in flower. However, agricultural chemicals are particularly liable to cause serious bee mortality when applied to flowering brassicas because these crops have an open flower and attract bees in very large numbers. So it was considered that a field experiment was necessary before it could be decided whether or not thiodan was safe to apply to brassicas in flower.

Experiment

Areas

The sprays were applied to chou moellier seed crops about five miles apart in the downlands country a few miles south of Duntroon in the South Island. The seed crops, typical for the district, were in full flower when sprayed and were the main source of nectar and pollen for bees from the experimental apiaries. Both crops were growing in fine sandy loam.

Thirty-seven medium-strength hives of bees were established 300 yards from one crop of five-and-a-half acres, all of which was sprayed with DDT. The chou moellier in this crop was of the giant type up to 7 ft in height while the other crop was of the shorter-growing type.

Forty medium-strength hives of bees were established half a mile from the other crop of 25 acres. One acre only of this was sprayed with thiodan.

The location of hives in the district surrounding the crops was known and indicated that most bees on the treated crops came from the experimental apiaries.

Application of Sprays

DDT. DDT emulsion was diluted with water to give 2 lb of 100% p.p.i. DDT per 7 gallons. This dilution was then applied from the air at the rate of 7 gallons per acre to the whole of the five-and-a-half acre crop from a height of about 6 feet. Application finished at 9.15 a.m. on 18 October (under perfect conditions). An overnight mist persisted until 8.30 a.m., and at the time of spraying the crop was very damp and covered with drops of dew, but it dried out rapidly after application. A few bumble bees but no honey bees were on it at the time of spraying.

Thiodan. Only a small volume was available for tests. A 20% emulsion was diluted with water to give 1.2 lb of 100% thiodan per 7

gallons all of which was applied from the air to an acre of the 25-acre crop. Application finished by 9 a.m. on 18 October, conditions being the same as when the DDT was applied.

Counts of Field Bees

Counts of field bees were made in representative sections of the crop sprayed with DDT, and in the sprayed and unsprayed areas of the other crop as described by Palmer-Jones *et al.* (1957). The total bee counts obtained for 400 sq. yd were multiplied by 12.1 to give the bee densities per acre plotted in Figs. 1 and 2.

RESULTS

Counts of Field Bees

Crop Treated with DDT. Weather favoured bee activity on 15, 16 and 17 October and high bee counts were obtained (Fig. 1). On the 18th, when the spray was applied, the weather was fine and bee counts should have equalled those of the day before. They were much lower, however, and on the 19th, when weather conditions were perfect for bee flight, counts were negligible. Rain fell on the nights of the 20th, 21st, and 23rd (23, 34, and 5 points). Conditions were unfavourable for bee activity from the 20th to 24th inclusive. No observations were made on the 25th but counts on the 26th, which was fine, showed a normal density of bees on the crop.

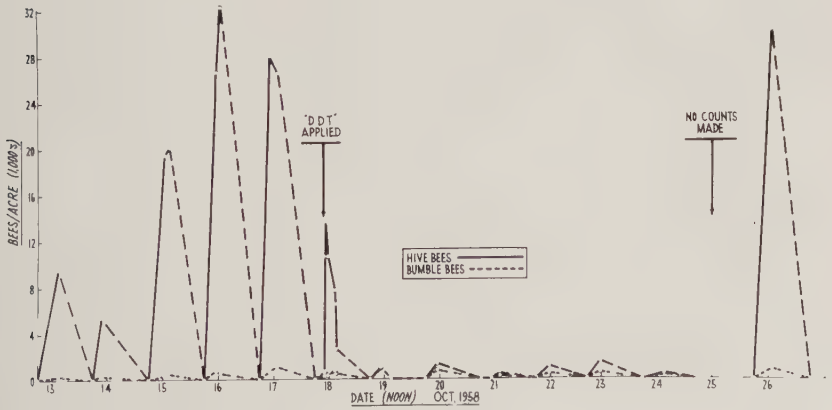

Fig. 1.—Hive and bumble bees per acre on crop treated with DDT.

Crop Treated with Thiodan. The crop was close to the one sprayed with DDT and so weather and other conditions were similar. But although over four times the area of the crop sprayed with DDT it was served by only three more hives. Consequently bee counts throughout the period of observation were lower. Counts were the same on the portion sprayed with thiodan as on the rest of the area (Fig. 2).

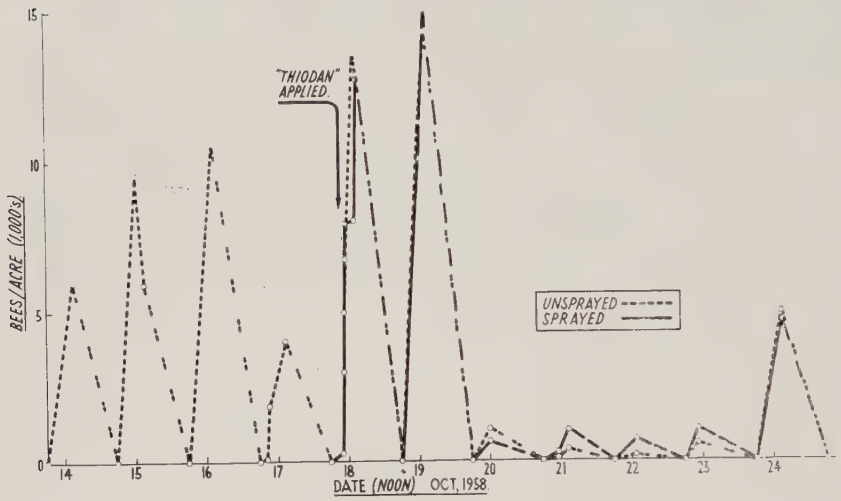

Fig. 2.—Hive bees per acre on crop treated with thiodan.

Effect of Insecticides upon Field Bees

The toxic action of the insecticides was studied by picking field bees off the crops and placing them in cages provided with feeders holding sugar syrup. These cages were kept under observation in an empty storey above a hive.

DDT. On the day this was applied 48 bees were collected in the morning and 20 in the afternoon; those collected in the morning showed a mortality of 17 bees (35%) and the others a mortality of 8 (40%) after 48 hours. The normal mortality after 48 hours is approximately 4%.

On the day following application (19th) 26 bees were collected in the morning. The mortality after 48 hour was 9 (35%). The mortality in 25 bees collected on the 23rd was 3 (12%) after 48 hours.

Mortality was nil after 48 hours for 24 bees collected on the 26th.

Thiodan. Fifteen bees were collected in the morning of the day of application; mortality after 48 hours was 9 (60%). Thirty bees were collected at noon on the following day (19th); mortality after 48 hours was 20 (67%).

Twenty-five bees were collected on the afternoon of the 24th: mortality after 48 hours was 2 (8%).

Bumble Bees

All bumble bees observed on the crop sprayed with DDT were *B. terrestris* except for two which were *B. ruderatus, B. hortorum,* or *B. subterraneus* sub-sp. *latreillellus,* it not being possible to distinguish between these species in the field. All bumble bees observed on the crop sprayed with thiodan were *B. terrestris.*

Bumble bees were counted on the crops in the same way as honey bees (Fig. 1). At the time the DDT spray was applied there were numerous bumble bees on the crop, but there was no evidence of mortality; bumble bee counts gave no indication of repellency even on the day of application. In the case of the field sprayed with thiodan there was no evidence that it caused bumble bee mortality or repelled them. But it must be remembered that only one acre of a 25 acre crop was sprayed and bumble bees showing symptoms of thiodan poisoning could have been overlooked.

Maximum counts of bumble bees were 1,113 per acre on the field sprayed with DDT and 339 per acre on the one sprayed with thiodan.

Behaviour of Honey Bees on Crops, and Repellency

Although both crops smelt strongly of insecticides on the day of application, bees visiting their flowers behaved normally.

DDT. Bees were repelled on the day of application and much more markedly on the following day. Bee counts made along the edge of the crop where the smell of DDT was not strong were always much higher than ones made further in. These counts provided evidence that repellency continued for a further four days in spite of falls of rain. Eight days after spraying there was no evidence of repellency.

Thiodan. Thiodan did not repel bees.

Effect of Insecticides upon Colonies

A few dead bees were observed outside some of the hives near the crop treated with DDT. However, no adverse effect on adult bees or brood in these hives and the others in the apiary was observed during the course of the experiment or later.

No adverse effect on adult bees or brood in the apiary near the crop sprayed with thiodan was observed during the course of the experiment or later.

Bees on both experimental areas collected pollen extensively after the sprays were applied.

DISCUSSION

On the day the DDT was applied a maximum bee count of over 13,000 per acre was obtained in the morning, but soon after noon it dropped to only 8,000. The following day was suitable for maximum bee activity and counts of over 32,000 bees per acre would have been expected. But the maximum count was only 1,000. Reduced counts were recorded for 6 days after spraying. Although mortality occurred in field bees collected from the crop, it was not very high and the hives were not weakened; when repellency ceased a count of 28,000 bees per acre was immediately obtained although the crop was seeding. So it is apparent that lessened bee activity on the crop after spraying was due to the DDT acting as a repellent, and not to bee mortality.

Palmer-Jones *et al.* (1954) found that DDT dust repelled bees from white-clover pasture for 3 days and Palmer-Jones and Forster (1958) showed that a DDT spray repelled bees for one day from lucerne. The plants in a chou moellier crop grow very high and close together and DDT emulsion on it would be much more protected from the drying action of winds than it would be on a short-growing crop such as lucerne.

A mixture of two commercial DDT emulsions was used in this experiment. Both preparations were different from that used on lucerne (Palmer-Jones and Forster 1958) so it is apparent that repellency is due to the DDT alone in these formulations.

The DDT did not repel bumble bees and apparently they suffered no mortality.

It is considered that DDT emulsion, if applied before bees visit a flowering brassica crop, will cause only slight mortality. It should be valuable for use when a crop must be treated urgently to save it from destruction by pests.

Palmer-Jones (1959) found that thiodan applied to broad beans at the rate of 5.6 lb in 56 gallons of water per acre repelled honey bees for three hours. In this experiment 1.2 lb of thiodan applied per acre did not repel honey bees or bumble bees.

No field bees died through contact with thiodan spray on the broad beans, but although less thiodan was applied to the chou moellier it caused more than 50% mortality for 2 days after application and some mortality even a week later. Petals protect the nectaries of the bean flower from contact with sprays but the chou moellier flower is a very open one which sprays can enter. The difference in flower structure between the two crops is probably the cause of this apparent inconsistency.

No adverse effect was observed on adult bees or brood in the apiary used for the thiodan experiment. But it must be remembered that the bees from this apiary were spread over a 25-acre crop only one acre of which was sprayed. Thiodan, unlike DDT, exerted no repellency and was also more lethal to field bees. It is, therefore, considered unsafe to apply thiodan to flowering brassica crops.

The DDT emulsion was applied very efficiently but the volume (7 gallons per acre) was insufficient to cover the crop adequately and make contact with all the aphids infesting it. Much more efficient coverage would have resulted if the DDT had been applied in a larger volume, say 30 gallons per acre. A greater volume of liquid per acre could be applied more cheaply and efficiently if the rate of application per acre was increased rather than if the plane flew more times over the crop. It would be necessary to fit more powerful pumps in planes and use larger spray nozzles on the booms to increase the rate of application. The desirability of introducing such changes in standard equipment can be decided only by experts in this field and we merely wish to draw attention to the matter.

CONCLUSIONS

It is considered that a DDT spray, if applied before bees visit a flowering brassica crop, will cause only slight mortality. It should be valuable for use when a crop must be sprayed urgently to save it from destruction by pests.

Thiodan should not be applied to flowering brassica crops.

ACKNOWLEDGEMENTS

The authors are grateful for the co-operation of Messrs. J. H. Pollock, Kokoama, and J. D. Simpson, Tokarahi, on whose farms the experiments took place; and Messrs. J. E. Rawson, Oamaru, and R. G. Rawcliffe, Corriedale, whose apiaries were used in the experiments. They are indebted to Messrs. J. G. Richards and R. K. Darwin, Instructors in Agriculture, Oamaru.

Messrs. Ivon Watkins Ltd., New Plymouth, kindly supplied us with thiodan for the trial.

Mr A. L. Bryant, Animal Research Station, Wallaceville, drew the figures.

REFERENCES

Palmer-Jones, T.; Bartrum, F. A.; Forster, I. W.; Harrison, D. L. 1954: Effect on Honey Bees of DDT plus Superphosphate Applied as a Dust to White Clover Pasture. *N.Z. J. Sci. Tech. A36:* 177-92.

Palmer-Jones, T.; Forster, I. W. 1958: Effect on Honey Bees of DDT Applied from the Air as a Spray to Lucerne. Notes on Lucerne Pollination. *N.Z. J. agric. Res. 1:* 627-32.

Palmer-Jones, T. 1958: Laboratory Methods for Measuring the Toxicity of Pesticides to Honey Bees. *Ibid. 1:* 290-300.

Palmer-Jones, T. 1959: Effect on Honey Bees of Thiodan Applied to Broad Beans in a Cage. *Ibid. 2:* 229-33.

Palmer-Jones, T.; Forster, I. W.; Griffin, L. A. M. 1957: Effect on Honey Bees of Metasystox Applied from the Air as a Spray to Chou Moellier. *N.Z. J. sci. Tech. A38:* 752-69.

PASTURE MANAGEMENT TRIALS ON UNPLOUGHABLE HILL COUNTRY AT TE AWA

II. RESULTS FOR 1951-57

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Summary

Further results of trials involving oversowing, topdressing and grazing management practices on steep unploughable hill country with an original carrying capacity of about 1.5 ewes per acre, are presented. Pasture improvement has been recorded by frame measurements to determine herbage yields, by herbage dissection, and also point analyses to determine botanical changes. With improvement in pasture, carrying capacity has increased markedly without detriment to stock thrift. All sheep were weighed monthly, and fleece weights were recorded.

Introduction

A previous report gave details of the establishment of the experimental area, climatic conditions, and the results obtained during the peroid 1948 to 1951 (Suckling 1954). The present paper deals with the results obtained over a further six-year period with some modifications made to the original design. These modifications were found necessary because the general topography of the country brought about management difficulties such as the lack of utilisation of pastures on shady faces in paddocks containing both sunny and shady aspects.

Climate

Rainfall

Fig. 1 and Fig. 2 show the rainfall distribution for the years 1948-56. The annual rainfall (inches) averaging 42.51 for the period under review has been as follows:

1948	43.81
1949	48.11
1950	39.37
1951	43.83
1952	42.68
1953	41.93
1954	32.97
1955	42.37
1956	47.49

The average monthly distribution of rainfall is fairly evenly spread throughout the year (Fig. 2). During the summer months pastures frequently reach wilting point on the sunny faces, owing largely to the angle of slope and the sandy, naturally free-draining soil type. The summer months of 1954, 1955, and 1956 were "droughty", rainfall being spread lightly throughout these months. During these seasons subterranean clover seed germinated after light falls of rain, only to

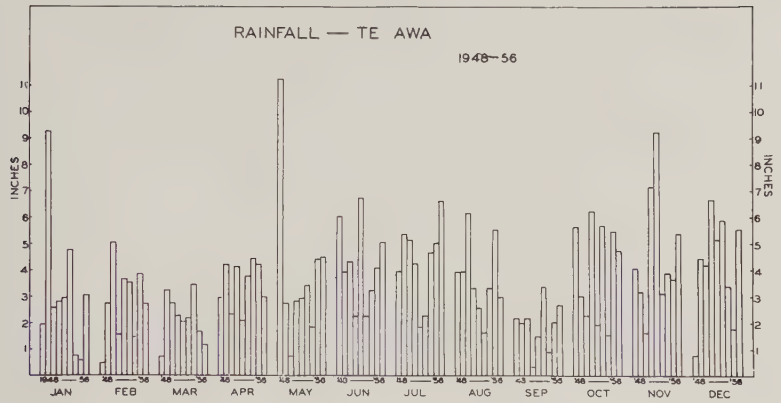

Fig. 1.—Distribution of rainfall, 1948-1956.

shrivel up in subsequent dry and windy periods. On the other hand, in a "wet" summer, this annual species has been seen to persist until new seedlings have established. Hence production can be markedly affected by summer rainfall. In years of heavy winter rainfall, "pugging" of pastures by stock has been evident with a probable greater incidence of surface runoff and slipping.

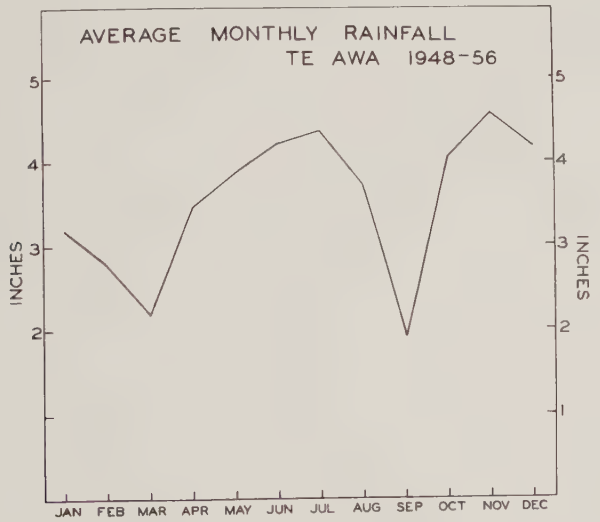

Fig. 2.—Average monthly distribution of rainfall, 1948-1956.

Earth Temperatures

Fig. 3 shows the mean monthly earth temperatures at 4 in. and 8 in. depth for the period 1949-56. Earth temperature at 8 in. depth did not rise as high as the 4 in. temperature during the summer months. Conversely, in winter, soil temperatures at 8 in. depth were not as low as those recorded at 4 in.

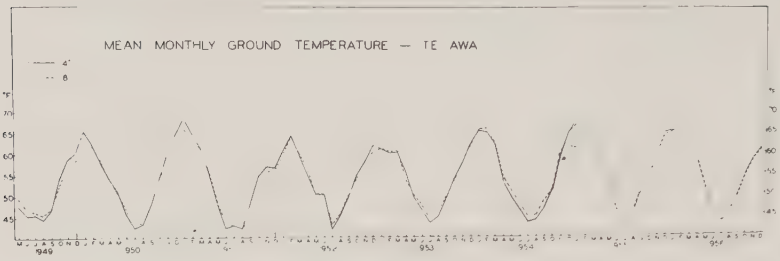

Fig. 3.—Comparison between 4 in. and 8 in. earth temperature on a hilltop, at 9.30 a.m.

Earth temperatures have been recorded regularly since 1949 on a flat hilltop, a sunny face, and a shady face. Mean annual 4 in. temperature for the 8 years on the three sites were:

Hilltop	54.5°F
Sunny face	55.3°F
Shady face	51.7°F

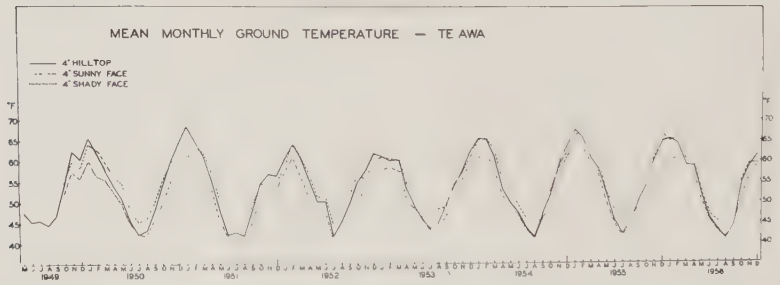

Fig. 4.—Relationship between earth temperatures at 4 in. on a hilltop, shady face, and sunny face, at 9.30 a.m.

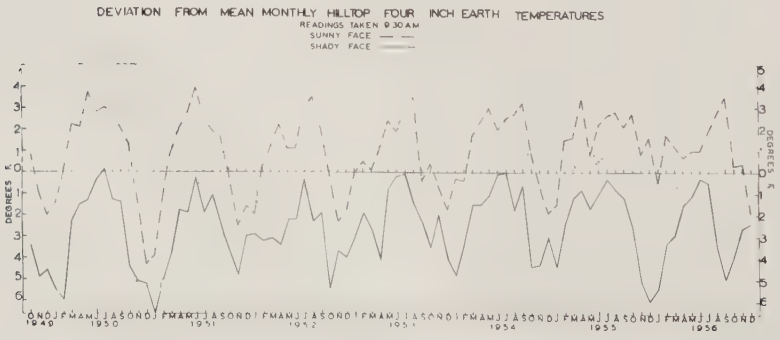

Fig. 5.—Mean deviation each month from hilltop 4 in. earth temperature.

Fig. 4 shows mean monthly earth temperature on the three sites while Fig. 5 shows the mean deviation each month from temperatures recorded on the hilltop. Fig. 5 shows that 9.30 a.m. earth temperatures at 4 in. on the sunny face are consistently higher than on the hilltop during winter, but are lower during summer. This is probably due to the angle of the sun in relation to the various aspects. In winter the sun rises in a north-easterly direction, so that in early morning there is very little direct sun on the shady faces, while the hilltops receive the sun's rays at an oblique angle. On the other hand the sunny faces receive the full benefit of early morning sun. In summer, however, the sun rises in the south-east, and the shady faces and hilltops receive early morning sun before the sunny faces. These differences in temperature can result in marked differences of growth on the various aspects. This was reflected in stock grazing on the sunny and shady faces; the sunny faces produced more feed during the winter and spring months than shady faces where the mean July temperature dropped to 42.3°F. Comparative means for the 8-year period on the hilltop and sunny face in July are 42.8°F. At Jealott's Hill in Britain, Halliday and Sylvester (1950) have shown that practically no growth occurs when soil temperatures at 4 in. are below 42°F. The figures above would therefore indicate that pasture growth was at a comparative standstill only during July on the shady faces and hilltop, but growth continued although at a reduced rate on the sunny faces.

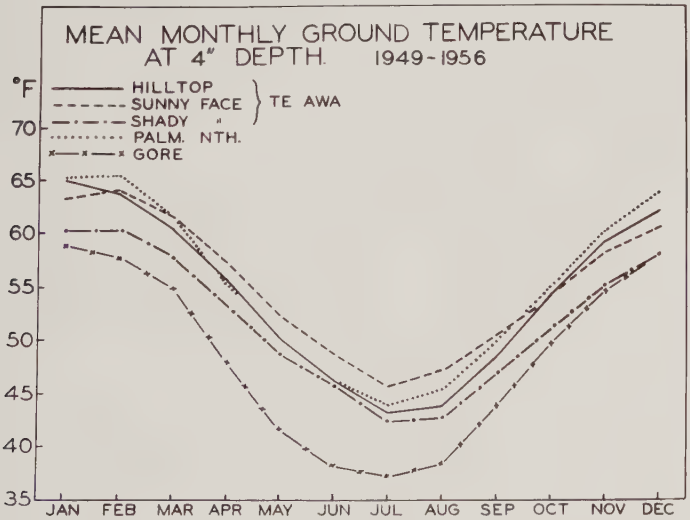

Fig. 6.—Mean monthly ground temperature at 4 in., 1949-1956.

Fig. 6 shows the mean monthly 4 in. earth temperature on the various sites at Te Awa, compared with those taken on the flat at Palmerston North and Gore over the same period. The influence of aspect, altitude, and latitude may be compared. Palmerston North latitude 40°23'S., altitude 110 ft above sea level: Te Awa 40°07'S. and 1,050 ft above sea level; and Gore 46°06'S. and 230 ft above sea level.

The graph shows that the sunny faces at Te Awa, although at 1,050 ft altitude, are warmer than Palmerston North during March to September, but are cooler from October to February. The hilltop at Te Awa ran fairly parallel in temperature with Palmerston North, in autumn, winter, and spring but was somewhat cooler in the summer months.

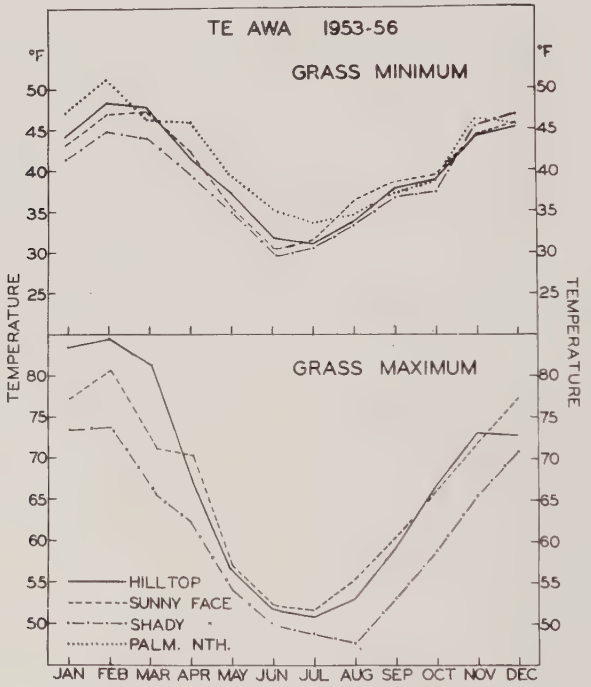

Fig. 7.—Grass minimum and grass maximum temperatures recorded on a hilltop, a sunny face, and a shady face. Grass minimum temperatures are compared with those recorded at Palmerston North.

Fig. 7 shows the monthly grass minimum temperatures on the three aspects for the years 1953-56, the mean for the four years being: hilltop, 40.2°F; sunny face, 40.8°F; shady face, 38.9°F.

The maximum thermometer readings have been included for interest only, as they do not conform to any standard measurement as laid down by the New Zealand Meteorological Service. The readings were taken with the mercury bulb buried $\frac{1}{2}$ in. in the soil, and serve to furnish some information on temperatures on the surface of the soil under grass grazed short by sheep. The annual means for the three sites are 65.2°F for the hilltop, 66.1°F for the sunny face, and 58.5°F for the shady face. Temperatures up to 120°F have been recorded in the summer.

Topography

Soil type and topography were described in the previous report. Briefly, the soil is classified as Raumai sandy loam (11H) on the easy slopes and hilltops, and Pohangina sandy loam (118a) on the steeper and more broken hillsides. For the most part the area is deeply dissected with a gully running from east to west, and comprises two northerly slopes and one southerly slope. The highest point is 1,050 and the lowest 700 ft above sea level.

The hillsides generally have eroded deeply and are still subject to periodic slipping during winter. Seepages along the length of the hillsides occur about midway from the top and bottom of the slope (Fig. 8).

Fig. 8.—Aerial view of the research area looking east toward the Ruahine ranges—note gullies in foregound.

RESEARCH PROGRAMME

During the period covered in this report, the programme outlined in the previous report was continued. Investigations were aimed primarily at determining the system of grazing management which would give both maximum production and the best spread of production throughout the year. Measurements were continued on effects of over-

sowing and topdressing, periodical spelling, and different systems of grazing, particularly continuous set-stocking and rotational grazing.

In the previous report, a plan showing the layout and subdivision of the area was presented. Because of difficulties encountered with that layout, the programme was revised in 1951. In the original plan the rotational grazing areas and other treatments consisted of both sunny and shady faces. It was apparent after the trial had been in progress for two years that some modifications would be necessary. Paddocks that included both aspects were not fairly comparable with those that had only one aspect. Difficulty was also experienced, with the comparatively small flock, in controlling pasture growth with only four paddocks in the rotation. At low stocking rates the pastures became patch-grazed, rather than uniformly grazed, particularly during the spring and summer months. This caused relative ill-thrift in the rotationally grazed ewes, no doubt because they were restricting their grazing to a reduced area of palatable pasture. It was therefore found necessary to subdivide the area further into 5-acre paddocks in order to increase the number of ewes per acre at any one grazing, and to separate sunny and shady faces. In this way better utilisation of the pastures was achieved as well as a more direct comparison with the continuously grazed paddocks.

Fig. 9 shows the revised layout which was completed during July 1951.

Fig. 9.—Layout and subdivision of the 180-acre research area for the years 1951-54. Paddocks 1, 7A, and 7B are unimproved, i.e. no seed or fertiliser, the remainder were oversown and topdressed. Paddocks 7B to 14B are shady faces, the remainder sunny faces, with the exception of paddock 6 and the 50-acre paddock which have both sunny and shady aspects.

MODIFIED PROGRAMME

Rotational grazing on a regular shift basis had been practised since 1948. Although paddock numbers were increased in 1951 and a further period of rotational grazing carried out, ewe and lamb thrift was not as satisfactory as it was on the set-stocked areas. In 1953, instead of both flocks rotating continuously through lambing, one flock was set-stocked from lambing to weaning. It was soon apparent that the ewe and lamb daily live-weight gains, and lambs weaning weights were superior on the set-stocked area to those on the continuously rotated area. It would appear that lamb thrift is adversely affected by regular shifts, probably through mismothering and fluctuating planes of nutrition, causing scouring and general dietetic upset. It was therefore decided, after six years of continuous rotation, that as no apparent advantage had been gained by the system, a further modification should be made.

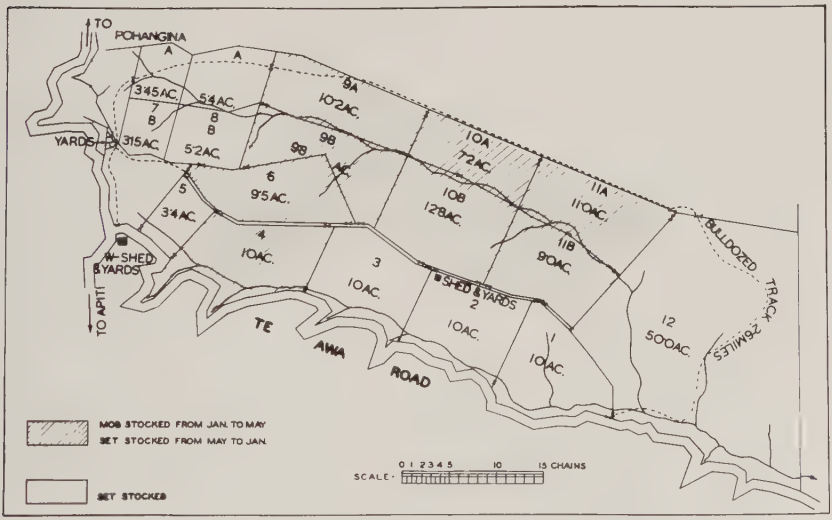

Fig. 10.—Layout and subdivision of the 180-acre research area for the years 1954-57. Paddocks 1, 7A and 7B no seed or fertilisers, the remainder oversown and topdressed. Paddocks 7B to 11B are shady faces, the remainder sunny faces with the exception of paddocks 6 and 12 which have both sunny and shady aspects.

Fig. 10 shows the modified layout for the period 1954-57 when a compromise was made between continuous set-stocking and continuous rotational grazing.

The fifty-acre paddock, which had been under separate management since 1948, was set-stocked at four ewes per acre in 1955. Because of suggestions that 5- and 10-acre paddocks would automatically carry more stock than larger farm-scale paddocks, it was of interest to compare ewe thrift on the fifty-acre paddock with that of the smaller experimental paddocks, under similar set-stocking management,

Fencing and Bulldozed Tracks

Additional subdivision was carried out during the autumn of 1951, involving approximately 57 chains of new fencing. All existing subdivisional fences, erected in 1948, were showing signs of deterioration, and needed constant attention to keep them stock proof.

A further difficulty was experienced with red birch (*Nothofagus fusca*) fence posts which have proved to be unsuitable for this area. After 5 years, several of these posts had rotted off at ground level, and during the past 3 to 4 years a large number of the original posts have been replaced. It would appear that this type of timber has an average life of only 7 years at Te Awa.

The 2½ miles of bulldozed tracks, which originally required a great deal of attention, have not over the last 5 years required much further work. For the most part, the tracks have grassed satisfactorily and only occasional scouring on the steeper slopes has necessitated regrading work.

Stock Dams

With the additional subdivision of the 130-acre area into 5-acre paddocks, water supply problems became apparent, particularly on the sunny faces, where stock access to the gullies had been prevented. Seepage areas provided small quantities of water for sheep, but the problem has not yet been overcome with regard to cattle. It is necessary during dry spells to graze cattle in only those paddocks where adequate water was available. This naturally restricted movement of stock at a period when roughage and weeds could be crushed most successfully. However, the hills are very steep for stock dams and a piped supply from a main reservoir would be too costly.

Of the five dams constructed in the valley bottoms, all except two have silted up and are now useless. The most satisfactory stock dam has proved to be that in paddock 14A where a small area of flat ground had been excavated. During dry weather all other dams have dried up. Fortunately, dry spells in this district are of short duration, otherwise more difficulty would be experienced.

Sunny and Shady Faces

Temperature differences of up to 5°F have been recorded between sunny and shady slopes during the winter, which produce differences in the vegetation between the two aspects. Generally speaking, the shady slopes have in the past been regarded as almost a liability because the animals tend to congregate on the sunny slopes even when these are severely overgrazed. In the summer months the sunny faces become very dry and coupled with over-grazing the better species of grasses and clovers become depleted. It is at this time of the year when pastures are dry and open that intense rainfall is occasionally experienced. Such heavy rainfall on open turf has led to widespread surface slipping and slumping as can be observed on sunny faces in many districts. In contrast, the shady faces, because of the cold conditions associated with such areas, do not attract stock; thus weeds such as hard fern, bracken

fern, and manuka, grow unchecked. The pasture becomes long and rank, and even more unattractive to stock, forcing them more and more on the already overgrazed sunny slopes.

A logical remedy is to fence and graze them separately so that each aspect can be managed to give maximum production. At Te Awa, the problem as outlined was acute and in order to achieve maximum utilisation on sunny and shady slopes, it was necessary to subdivide the sunny and shady slopes by fencing along the gully bottom. It was realised that such subdivision could cause additional labour requirements for fence repairs. However, the results achieved more than compensated for the few hours spent in repair work each winter.

Since subdivision was completed in 1951, management problems on the rotationally grazed areas have been greatly simplified and obvious advantages have resulted. The shady faces, after heavy crushing with cattle, produce excellent feed for sheep during summer when the sunny slopes are dry and unproductive. Moreover, the shady slopes benefit markedly from stock concentration and controlled grazing while overgrazing of the sunny slopes is prevented. On the other hand, the sunny slopes are more productive during the winter and spring months. Since subdivision has been completed, the direct benefit has been spectacular. On shady slopes which carried practically no stock in 1949-51, it was possible to graze permanently $4\frac{1}{2}$ ewes per acre in 1954-57.

PASTURE IMPROVEMENT

Oversowing

In the previous report, oversowing rates and mixtures were given for the 180-acre area. No further oversowing has been done on the area since the original sowing of the 50-acre paddock in 1946 and the 130-acre area in 1949, except for one shady-face paddock (8B) in early April 1953. The initial oversowing on this paddock had been unsatisfactory owing to the large amount of long unpalatable herbage and thick moss on the area, at the time of seeding, causing a poor strike of the oversown clovers. Subdivision of the paddock into sunny and shady faces made it possible to graze 25 head of cattle on the area until all roughage had been removed. After the paddock was grazed hard, seed was sown and both sheep and cattle confined on the pasture for three days so that the seed could be tramped into the soil. Following oversowing, the pasture was not allowed to grow to more than $1\frac{1}{2}$–2 in. before being grazed by sheep. A good strike of oversown clovers was achieved and this was followed up with a summer spell to reseed the pasture in the summer of 1955.

The clover mixture used was the same as that in the original sowings in 1949, except that no grass seed was included in the mixture.

2 lb certified N.Z. white clover
2 lb certified N.Z. Montgomery red clover
2 lb subterranean clover (1 lb Mt Barker, 1 lb Tallarook)
$\frac{1}{2}$ lb lotus major [*Lotus uliginosus*]

Ryegrass Oversowing Trial

Suckling (1950) reported on the strike of oversown grass and clover seed on hill pasture. Observation and experimental work concerned with oversowing, and the management of pastures both before and after oversowing was discussed by the author in 1951. In the Te Awa report of 1954 reference was made to the failure of grass species to establish successfully from these oversowings. It was concluded that:

(1) Pastures should be short grazed prior to sowing to open up the sward and thus allow the seed to reach the soil surface.

(2) Clover species established significantly better when sown on short rather than long pasture. Long pasture had a decided suppressing effect on the smaller clover seedlings.

(3) Management following oversowing should be aimed at preventing grass smother of the clover seedlings, either by continuous grazing or by intensive rotational control.

The results of these trials closely followed those obtained by Sears (1949) as Grasslands Division, where vigorous grass seedlings were shown to cause significant losses in clover seedlings, during the establishment stage.

Successful clover oversowings have been made by following this procedure. However, further observation regarding the failure of grass to establish from seed mixtures containing both grass and clover seed have shown that these conditions, although applicable to clover oversowing are not entirely satisfactory for grass. It was apparent, from previous oversowing trials on hill pasture with ryegrass seed, that the fertility requirement of ryegrass seedlings was greater than for the establishment of clover species; therefore fertility should first be built up by topdressing, oversowing with clover seed, and increasing stock numbers, to the stage where fertility levels were sufficiently high to support strong ryegrass growth.

Early grazing to prevent smother of clover, particularly where pastures have been improved by topdressing, and where an autumn flush of pasture is experienced, is necessary for clover establishment, but grass seedlings were found to be pulled out by the roots before they had become firmly established. To overcome this difficulty the oversown area would have to be spelled for a sufficiently long period to ensure a firm roothold before grazing takes place.

In order to test this, a grass oversowing trial was laid down in autumn 1954. A 5-acre paddock that had been previously oversown with clovers, topdressed with superphosphate, and heavily stocked with sheep and cattle, was closely grazed. Some measure of hoof cultivation was achieved by holding both sheep and cattle on the area for a period when there was practically no cover. Early autumn rains aided this hoof cultivation and produced quite a reasonable seed bed.

Alternating strips of perennial ryegrass and short-rotation ryegrass at 10 lb per acre were sown down the hillside, with control strips between each sown area, with three replications. Stock remained on the area for a further two days to tramp in the surface-sown seed. The

area was then spelled for a period of six weeks when establishment counts were taken at random in 30 square-foot quadrats on each strip.

The results which are expressed as means of 90 quadrats for each treatment are shown in Table 1.

TABLE 1. ESTABLISHMENT OF OVERSOWN RYEGRASSES

Species	Estimated No. of Viable Seeds Sown per sq ft	Mean Estab. per sq ft		% Estab. of Seed Sown	
		6 wks	12 wks	6 wks	12 wks
Perennial	57	14	9	24	16
Short-rotation	53	15	10	28	21
Control	—	0.2	0.2	—	—

It will be seen in Table 1 that a satisfactory establishment rate was achieved. Defoliation took place six weeks after sowing, and a further count was taken to determine survival rates at twelve weeks. Some losses had occurred and no doubt some delayed germination had taken place. Similarly, a small amount of volunteer ryegrass may have established.

Observations showed that perennial ryegrass was still small at 12 weeks, but appeared healthy and likely to survive the winter months. Short-rotation ryegrass was stronger and more vigorous than perennial. It was apparent that most of the established seedlings were in hoof depressions. The steep banks between stock tracks, where no tramping took place, had however, low establishment rates. Subsequent inspection showed that survival rates on these sites had also been adversely affected by low fertility and lack of soil moisture during the summer period.

Difficulties will of course be experienced if drought at the time of oversowing makes the soil too hard for hoof cultivation; in some seasons false strikes, with light showers followed by dry periods will also take a toll of oversown seedlings. However, with suitable weather conditions and stock management it is possible to establish grass successfully on hill pastures.

Fertiliser Treatment

Trials carried out on the area indicated that phosphate was the main mineral deficiency limiting production, hence, over the period 1951 to 1957, annual dressings of superphosphate at 2 cwt per acre were applied. As a check on phosphate responses, additional trials were carried out periodically on a paddock where phosphate had been applied each year in the past.

These observation trials showed additional responses indicating that the annual 2 cwt dressing was insufficient to make good the deficiency even though the area has received annual dressings which now total 18 cwt of superphosphate per acre over nine years (Fig. 11).

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TABLE 2. AVERAGE ANNUAL GROUND COVER BY SPECIES IN PADDOCKS 1, 2 AND 3*
(Hits per 100 points examined on 5 fixed comparable transects in each paddock)

Species	Ryegrass and Dogstail			Browntop			Yorkshire Fog			Sweet Vernal			Other Grasses†		
Paddock	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
1949	12	17	18	29	31	30	7	7	8	18	12	17	20	29	30
1950	15	25	26	32	25	30	9	6	3	24	15	17	28	25	37
1951	18	38	22	45	36	42	12	8	12	25	15	23	34	36	45
1952	18	42	20	42	31	38	18	13	16	30	17	25	36	26	42
1953	23	42	18	44	30	47	20	13	27	31	11	19	44	34	33
1954	21	44	26	34	27	39	12	9	14	11	6	13	33	23	19
1955	21	38	32	47	30	39	12	6	6	10	5	10	35	20	16

* P 1 No seed or fertiliser, set stocked. P 2 Oversown and topdressed, set stocked.
‡ Paddock 1 did not contain red clover, subterranean clover or lotus major throughout
† *Other grasses:* Danthonia, Chewings fescue, cocksfoot, hairgrass, *Poa pratensis,*
§ *Other species:* Catsear, ribgrass, hawkweed, hawkbit, dandelion, selfheal, bidibidi, Californian thistle, winged thistle, marsh thistle, moss, rushes, *Carex* spp.

Fig. 11.—Topdressing by hand for the first three years of the trial after which aerial topdressing was practised. Superphosphate is being applied at the rate of 2 cwt. per acre.

Red Clover		White Clover			Suckling Clover			Subterranean Clover‡		Lotus major ‡		Other Species§		
2	3	1	2	3	1	2	3	2	3	2	3	1	2	3
2	1	3	8	4	6	12	12	1	2	0	0	7	6	5
4	2	4	22	15	8	9	7	7	3	1	0	6	5	3
3	6	6	22	26	10	13	17	7	2	2	5	17	14	10
1	6	5	27	31	8	5	8	16	5	4	12	28	16	20
1	7	10	26	26	7	4	1	14	1	6	16	34	17	8
1	5	15	24	33	8	3	3	17	3	8	12	32	17	16
2	2	14	15	29	11	4	6	20	5	5	8	25	23	17

P 3 Oversown and topdressed, set stocked, periodic spell.
the period.
Poa trivialis, Poa annua, goosegrass, paspalum.
sorrel, purging flax, cudweed, mouse-eared chickweed, dock, Scotch thistle,

Botanical Composition

Changes in pasture composition have been measured regularly by the point-analysis method (Levy and Madden 1933) and total dry-matter production by the frame-enclosure method.

Point Analysis. Table 2 shows the average annual ground cover by species for three comparable 10-acre paddocks on a sunny face. The

Fig. 12.—Unimproved pasture at the commencement of the trial peroid; sward was open, mossy, and weedy, with little clover present.

Fig. 13.—Improved pasture showing strong clover growth resulting from oversowing, topdressing, and appropriate pasture management to encourage clover.
(H. Drake photo)

figures shown are averages of point analyses from 10 permanently pegged transects in each paddock, taken seasonally each year over the period 1949 to 1955 (Fig. 12 and 13).

Paddock 1. From Table 2 it will be seen that, in the control paddock, ryegrass and crested dogstail, browntop, other grasses consisting largely of Chewings fescue, danthonia, *Poa pratensis,* hairgrass, and goosegrass, have gradually increased. Yorkshire fog increased markedly in the first five years, then decreased slightly by the seventh year although remaining at a higher level than in 1949. Sweet vernal increased up to 1953, then decreased by 1955 to a lower level than in 1949. White clover, suckling clover, and weeds all increased steadily over the period.

The observed overall result of continuous heavy stocking on unimproved pasture was a more dense turf, stronger white clover growth, and a gradual spread of introduced legumes, largely lotus major and subterranean clover, undoubtedly through cattle transferring clover seed from summer-spelled oversown areas. Although winter production limited further stock increases, i.e. from 1½ ewes in 1949 to 3 ewes in 1950, these ewes were carried satisfactorily with additional cattle grazing during spring and summer.

Paddock 2. This area was oversown in 1949 with clover seed and topdressed annually with 2 cwt per acre of superphosphate. Stock

carrying increased from 1½ ewes in 1947 to 5½ ewes set-stocked in 1955. Table 2 shows an increase in ryegrass, white clover, subterranean clover, lotus major, and weeds. Browntop and Yorkshire fog remained at a similar level to that recorded in 1949 while sweet vernal, suckling clover, and other grasses decreased in quantity. Montgomery red clover, which was oversown in autumn 1949, reached a peak in 1950, then declined under continuous heavy sheep grazing. White clover behaved similarly, reaching a peak in 1952, then becoming less dominant. The continuous heavy grazing largely prevented white clover from flowering and reseeding. Subterranean clover, on the other hand, thrived and was able to reseed under heavy grazing, thus tending to dominate the pasture during spring and early summer.

The overall result of this management was a highly productive hill pasture capable of carrying 5½ ewes per acre all the year round, but with a tendency to become invaded with strong tussock and weed species such as rushes (*Juncus* spp.) and sedges (*Carex* spp.).

Paddock 3. Pasture and stock management and carrying capacity were the same as on Paddock 2, except that stock were removed on two occasions in order that summer spells might allow the oversown clovers to reseed.

Table 2 shows that ryegrass and crested dogstail, browntop, Montgomery red clover, white clover, subterranean clover, lotus major, and weeds, all increased over the period, while Yorkshire fog, sweet vernal, other grasses, and suckling clover all decreased in ground cover.

It is apparent from the general stock thrift on this area that summer spelling, which improved the overall legume content, has also resulted in better grass vigour and a higher overall production. Subterranean clover did not respond to spelling and failed to reseed satisfactorily, possibly owing to damp conditions while seed was setting.

Effect of Site on Botanical Composition

At the commencement of the trial, fixed transects (each to provide 100 evenly spaced points) were pegged on each paddock, on sites chosen as typical of slips, easy slopes, sunny and shady faces, and stock camps. Sequential analyses on each of these sites give comparable data on botanical changes under the improvement programme over the eight-year period.

Table 3 shows pasture changes on various sites in autumn 1949 and 1957. The overall picture on all transects following oversowing and topdressing shows a substantial increase in ryegrass and crested dogstail, a reduction in danthonia, a slight increase in browntop and Yorkshire fog, and a rise in total clovers. Both bare ground and flat weeds decreased.

Slips. The pasture cover on the slips in the control paddocks did not improve to any marked extent over the first three years but has subsequently increased, mainly from volunteer grasses, such as Chewings fescue, browntop, Yorkshire fog, sweet vernal, and also weeds. Volunteer clovers were very slow to establish.

TABLE 3. PASTURE CHANGES ON VARIOUS SITES AUTUMN 1949 AND 1957

	Ryegrass		Dogstail		Cocksfot		Chewings fescue		Danthonia		Browntop		Sweet Vernal	
	1949	1957	1949	1957	1949	1957	1949	1957	1949	1957	1949	1957	1949	1957
Slips														
Unimproved	—	1	—	3	—	3	2	14	—	5	14	55	12	22
Improved	2	11	3	11	1	2	2	14	5	3	20	43	30	7
Stock Camps														
Unimproved	31	51	3	27	3	1	—	—	2	—	19	24	16	5
Improved	49	72	10	6	2	2	2	Tr	1	Tr	25	9	14	5
Sunny Faces														
Unimproved	5	4	4	9	6	1	10	24	2	8	17	52	32	10
Improved	3	25	13	15	3	2	13	14	12	17	41	37	17	6
Shady Faces														
Unimproved	1	10	3	6	—	1	30	7	—	4	34	40	11	11
Improved	1	11	10	21	2	2	14	12	11	3	35	42	18	3
Av. of All Transects	10	26	8	14	2	2	11	12	10	5	31	37	16	6

* Other grasses and other species as for Table 2.
† No red clover, subterranean clover, or lotus major present in 1949.

The fertilised and sown slips showed a steady improvement in the amount of oversown grasses, although, as on the unsown slips, volunteer grasses have also increased. The most obvious improvement in ground cover has been from the oversown clovers. Total legumes were 7 in 1949, 30 in 1951 and 48 in 1957. Bare ground has decreased from 30 in 1949 to 3 in 1957.

Stock Camps. Stock camps on the control paddocks showed an increase in ryegrass, dogstail, browntop, and Yorkshire fog, while sweet

Yorkshire fog		Other Grasses*		Red Clover†	White Clover		Suckling Clover		Subterranean Clover†	Lotus major†	Other Species*		Catsear		Bare Ground	
1949	1957	1949	1957	1957	1949	1957	1949	1957	1957	1957	1949	1957	1949	1957	1949	1957
1	13	—	4	—	—	3	—	2	—	1	17	29	8	13	32	6
8	19	11	6	1	2	23	5	4	8	12	2	8	12	7	30	3
24	31	5	24	—	7	24	1	Tr	Tr	—	5	6	15	8	—	3
21	33	—	16	Tr	8	24	1	—	Tr	Tr	7	5	12	2	—	—
14	8	3	3	Tr	1	9	1	9	1	Tr	1	18	13	15	15	1
9	14	1	6	—	3	23	6	2	9	7	4	6	26	9	3	—
24	23	1	15	—	17	20	3	—	1	—	7	27	21	6	—	6
17	31	1	10	Tr	12	21	3	1	2	—	2	14	13	5	6	3
11	19	4	10	Tr	6	20	5	2	5	3	7	10	21	8	9	1

vernal, cocksfoot, and danthonia decreased. White clover increased over the period from 7 in 1949 to 24 in 1957. In the improved pastures, the stock camps increased in ryegrass from 49 in 1949 to 72 in 1957, and in Yorkshire fog from 21 to 33. Crested dogstail, browntop, Chewings fescue, danthonia, and sweet vernal all decreased considerably. White clover increased from 8 in 1949 to 24 in 1957. Subterranean clover and lotus major seedlings were unable to compete on the high-fertility areas and failed to establish.

Sunny Faces. Sunny faces of the unimproved paddocks increased in Chewings fescue, browntop, and crested dogstail but not in ryegrass, cocksfoot, sweet vernal, or Yorkshire fog. White clover and suckling clover both increased over the period. Catsear and other species increased from 14 to 33. Pastures became more dense, there being a reduction in bare ground from 15 in 1949 to 1 in 1957.

The sunny faces of the improved paddocks showed increases in ryegrass, crested dogstail, and Yorkshire fog. Total clovers rose from 9 in 1949 to 41 in 1957, this increase being mainly from white clover, subterranean clover, and lotus major. Catsear decreased from 26 to 9, and other species increased from 4 to 6.

Shady Faces. Shady faces of the unsown paddocks showed increases in ryegrass, crested dogstail, browntop, and white clover. Flat weeds decreased, but "other species", consisting mainly of moss, increased.

The improved shady faces increased in ryegrass, crested dogstail, browntop, and Yorkshire fog. White clover increased over the 8-year period, from 12 to 21, and subterranean clover showed a small increase under the moist shady conditions, from 0 to 2.

Changes in Ground Cover on the 50-acre Paddock

Changes recorded for the 50-acre paddock were similar to those seen on the main area. Table 4 shows a summary of changes grouped under the same headings as for Table 3.

There has been an obvious improvement in pasture composition on the 50-acre paddock since the original oversowing in March 1946. Thirty-two permanent line transects were pegged at the time of oversowing and records have been kept periodically since that date. Groundcover changes were recorded by the point-analysis method and grouped into four classifications according to aspect and topography.

Slips. Bare slips have filled in satisfactorily with a good strike of white and subterranean clover. Lotus major has also increased. There have also been large increases in all the sown grasses, as well as from volunteer grasses. Both bare ground and weeds decreased markedly over the period.

Stock Camps. Ryegrass has increased from 30 to 83 and crested dogstail has decreased from 6 to 1. As fertility increased, so also did dogstail, but ryegrass eventually dominated on the stock camps and has now suppressed the dogstail. Browntop, Yorkshire fog, danthonia and Chewings fescue have all been suppressed by strong ryegrass growth. In the other grasses, *Poa trivialis* has increased slightly since improvement commenced. White clover has increased from 2 to 40. Subterranean clover was established in 1949 but gradually disappeared from the sward under high-fertility conditions, when ryegrass dominated the pasture. Lotus major failed to establish on the stock camp areas on the 50-acre paddock, as was the case on the 130-acre area. Total weeds were reduced from 19 in 1946 to 4 in 1957. The proportion of bare ground was observed to be influenced greatly by cattle treading during wet periods, and fluctuates accordingly.

TABLE 4. POINT ANALYSIS 50-ACRE PADDOCK. HITS PER 100 POINTS EXAMINED. 1946–57

Date	Description	Ryegrass	Cocksfoot	Crested dogstail	Yorkshire fog	Browntop	Sweet vernal	Danthonia	Chewings fescue	Other grasses	Total grasses	White clover	Sub. clover	Lotus major	Suckling clover	Total clovers	Catsear	Other species	Total weeds	Bare ground
Autumn	*Slips*																			
1946	(a) Unimproved	—	—	—	3	11	7	2	—	—	23	2	—	—	—	2	5	9	14	65
1948	(b) Improved	10	—	1	6	8	15	1	1	1	43	25	4	1	7	37	4	8	12	31
1949	(c) Improved	5	—	1	8	15	32	2	6	—	69	23	2	7	2	34	2	11	13	24
1951	(d) Improved	4	1	6	14	33	33	2	3	2	98	26	3	8	3	40	4	9	13	14
1957	(e) Improved	22	3	21	13	40	9	3	6	4	121	37	2	7	3	49	3	3	6	4
	Stock Camps																			
1946	(a) Unimproved	30	2	6	28	47	11	5	1	8	138	2	—	—	1	22	11	8	19	—
1948	(b) Improved	43	—	9	15	29	7	3	1	3	110	34	4	—	2	40	7	4	11	1
1949	(c) Improved	44	1	13	11	10	6	2	1	19	107	35	3	—	—	38	4	3	7	5
1951	(d) Improved	72	—	11	14	12	11	4	—	14	138	30	1	—	—	31	9	3	12	3
1957	(e) Improved	83	—	1	17	6	2	—	—	10	119	40	—	—	—	40	—	4	4	—
	Sunny Hillside																			
1946	(a) Unimproved	2	2	5	8	26	17	24	4	3	91	4	—	—	3	7	23	3	26	12
1948	(b) Improved	7	2	6	6	16	9	22	4	1	73	5	9	—	21	35	15	2	17	11
1949	(c) Improved	6	3	14	6	19	25	20	7	4	104	11	18	—	13	42	12	3	15	7
1951	(d) Improved	9	3	9	8	13	13	41	4	6	106	12	11	—	5	28	20	5	25	5
1957	(e) Improved	13	2	22	9	42	9	18	13	2	130	20	20	4	11	55	13	1	14	—
	Shady Hillside																			
1946	(a) Unimproved	—	4	4	10	59	16	7	3	1	104	4	—	—	1	5	22	6	28	5
1948	(b) Improved	4	1	7	4	36	5	4	5	—	66	16	3	5	10	34	13	8	21	8
1949	(c) Improved	2	2	21	5	37	22	9	5	1	104	25	7	13	8	53	9	8	17	6
1951	(d) Improved	15	1	24	10	53	10	17	5	1	136	21	3	7	1	32	15	11	26	2
1957	(e) Improved	19	1	31	12	33	18	10	5	1	130	36	1	22	2	61	5	1	6	2
Av. all Transects	1948	7	3	5	12	35	14	11	6	2	95	7	—	—	3	10	18	6	24	18
	1957	31	2	24	13	34	8	10	9	4	135	34	6	7	5	52	5	5	10	2

Sunny Faces. On the sunny hillsides, ryegrass and dogstail have increased. Browntop increased from 26 to 42 and Chewings fescue from 4 to 13. White clover did not increase as much on the sunny hillsides as on the shady, but subterranean clover rose from 0 to 20 on the sunny faces as compared with 0 to 1 on the shady faces over the 11-year period. Lotus major rose from 0 to 22 on the shady slopes, but only from 0 to 4 on the sunny slopes. Total legumes rose from 5 to 61 on the shady hillsides and from 7 to 55 on the sunny faces. Total weeds decreased more on the shady hillsides than on the sunny.

Shady Faces. Ryegrass, dogstail, white clover, and lotus major increased considerably with a corresponding reduction in bare ground and weeds. Subterranean clover was unable to compete with white clover and lotus major on the shady hillsides.

Overall Average 1948 to 1957. Large increases were shown for ryegrass, crested dogstail, white clover, subterranean clover, and lotus major. There was a reduction in sweet vernal, weeds and bare ground, while browntop, danthonia, and Chewings fescue remained constant over the 9-year period.

Natural Reseeding

The previous report gave details of the effect of spelling pastures in the spring and early summer, and of the legume-seed populations in the soil. It was shown that a substantial reserve of seed can thus be built up, provided that spelling follows soon after the original oversowing. Each paddock in the rotationally grazed areas was accordingly spelled once during the period 1951-57.

The number of paddocks spelled each year depended on the season. In a wet summer several paddocks were spelled, while in dry summers only one or two could be closed.

It was observed that pastures spelled early in the summer grew heavy crops of rank grass, which became unpalatable and difficult to remove by sheep grazing, and necessitated heavy cattle stocking with its consequent pugging. Autumn recovery was slow following such grazing and winter production was adversely affected. Following these observations, paddocks were shut up at different times, and the effects on growth observed. The objective has been clover-dominant growth producing a maximum amount of clover seed, which serves the dual purpose of reseeding clovers and of providing flushing feed for ewes. Shady faces have proved particularly successful, with ample clover flowering and seed setting, but without undue amount of unpalatable roughage.

From these different closing times, it was seen that for best results pastures should be close grazed until the middle or end of December, depending on the season. In dry summers, mid-December has proved satisfactory, but in wet summers, shutting up pastures even at the end of December resulted in an over-abundance of grass.

In the first week of March 1956, a large flock of ewes on the rotationally grazed area was turned on to spelled pastures on a sunny

face. The pastures had been saved for clover reseeding and for flushing the flock prior to tupping. At the same time, ewes that were permanently set-stocked on sunny faces suffered an outbreak of facial eczema (about 10% of the ewes being affected) but no eczema was observed in sheep on the spelled pastures which were then clover dominant with a small proportion of mature grass. It is of interest also that set-stocked ewes grazing on shady faces did not suffer from this disease.

Since shutting up dates have been delayed until the end of December, there has been much less necessity for cattle to clean up roughage following sheep grazing. It has also resulted in a rapid pasture recovery following grazing and a subsequent satisfactory winter production. Clover seedlings which germinate following autumn rains are not smothered by long grass and hence a more dense clover stand results. While the saved pastures are being spelled for reseeding, the ewes were automatically restricted to a smaller portion of the farm and consequently management was simplified at a time when there was a surplus of growth which was difficult to control. Rather than have the whole farm patch-grazed and running up to roughage, a portion is spelled whilst the remainder is adequately controlled. This management coincides with the necessity to reduce the condition of the flock in order that they may then be flushed for tupping.

During the period while the saved pastures are being grazed, the remaining paddocks are spelled, thus conserving fresh pasture which can be held for some time without becoming coarse and unpalatable.

HERBAGE PRODUCTION

In the first three years of the trial, three steel protecting frames were placed in each paddock for measurement of pasture production. Efficiency in pasture sampling was low, because of the extremely variable topography and plant cover. In 1952, eight frames were placed in each of seven paddocks in an endeavour to overcome this difficulty. Two frames were placed on each hilltop stock camp, and six frames on the hillsides. Wherever practicable, the grass under the frames was cut monthly and the frames moved to a different location nearby. On the rotationally grazed areas, and to a lesser extent on the set-stocked paddocks, because of patch grazing and consequent accumulation of unpalatable roughage, it was found necessary to trim each frame site before placing the frame on it.

Thus the cuts from under the frames were an estimate of pasture growth rather than of herbage consumption by the animal. Cutting at regular intervals did not give a comparison between the two management systems, as the grass from under the frames in the set-stocked paddocks was cut at approximately monthly intervals. Because of the various difficulties encountered in measuring production from rotationally grazed pastures, it was decided in 1952 to take measurements only on set-stocked paddocks in order to compare production from shady and sunny faces and improved and unimproved pasture.

TABLE 5. STOCK CAMP PRODUCTION 1952–56

Year	Paddock 1 Unimproved						Paddock 2 Improved					
	D.M. per acre	D.M. %	Botanical Constituents lb D.M. per acre				D.M. per acre	D.M. %	Botanical Constituents lb D.M. per acre			
			Ryegrass Dogstail	Other grasses	Clovers	Other species			Ryegrass Dogstail	Other grasses	Clovers	Other species
1952	10000	18.9	2500	6200	900	400	12400	16.4	3600	7600	1000	200
1953	17600	19.2	4800	11100	500	1200	21300	16.2	4900	14700	850	850
1954	12700	21.3	4600	7100	500	500	16700	21.3	6800	9200	500	200
1955	9600	22.1	3000	3900	1700	1000	13500	22.2	7300	4700	800	700
1956	1900	21.0	5000	5500	700	700	21700	19.6	9150	10650	1500	400
	Paddock 7B Unimproved						Paddock 10A Improved					
1952	11000	19.7	1500	8100	800	600	12700	19.8	2900	8100	400	1300
1953	21900	16.9	4000	17000	700	200	23900	15.9	3350	19800	250	500
1954	14000	19.4	4500	8800	400	300	15800	19.3	5400	9150	950	300
1955	15300	19.1	3500	9200	1300	600	24000	21.3	9400	12950	950	750
1956	17100	18.1	6500	9800	650	150	25000	18.6	14750	8250	1750	250

Hillside Production 1952–56

	Paddock 1 Unimproved						Paddock 2 Improved					
1952	2700	31.4	100	1950	300	350	6300	24.1	1000	3400	1400	500
1953	7300	24.2	850	5700	150	600	11500	21.0	2300	4850	3450	900
1954	5100	25.2	1550	2800	250	500	6300	21.5	1750	2900	1450	200
1955	4700	24.5	1550	2450	300	400	6100	22.7	1750	2050	1850	450
1956	5000	24.8	2100	2400	250	250	11200	21.0	4700	4050	1800	650
	Paddock 7B Unimproved						Paddock 10A Improved					
1952	3900	21.6	200	3250	100	350	7800	22.8	950	4600	1700	550
1953	8700	20.6	1400	6700	250	350	13300	18.7	2650	8650	1350	650
1954	4700	21.7	700	3200	300	500	8600	19.6	1450	4900	2050	200
1955	5200	22.3	1000	3050	700	450	7100	21.2	1400	3000	1900	800
1956	7000	20.8	1750	3850	750	6500	9600	19.6	4400	3750	950	500

Herbage from the frame enclosures was weighed and sampled for determination of botanical composition and dry weight. The dried samples were ground and aliquots of the dried herbage analysed for crude protein.

Table 5 shows annual grass production of the treatments and the contribution of the various species to the total yield.

Paddock 3 Improved						Paddock 7A Unimproved					
		Botanical Constituents lb D.M. per acre						Botanical Constituents lb D.M. per acre			
D.M. per acre	D.M. %	Ryegrass Dogstail	Other grasses	Clovers	Other species	D.M. per acre	D.M. %	Ryegrass Dogstail	Other grasses	Clovers	Other species
11500	16.7	1300	7600	2400	200	9300	16.8	1200	6000	500	1600
15100	18.0	2600	10600	1300	600	11700	19.8	1800	9100	700	100
15700	19.5	5800	8300	800	800	11750	21.3	2100	7650	1200	800
13600	20.6	4600	6100	1900	1000	12400	22.2	3600	6000	1100	1700
23400	20.6	11200	9100	2600	500	14300	19.4	4200	7400	1400	1300
Paddock 10B Improved											
11600	15.6	1750	9350	250	250						
20600	14.7	4550	14850	600	600						
20600	24.3	7000	11950	1250	400						
16400	21.1	5750	9000	1500	150						
23100	19.9	10600	11300	700	500						
Paddock 3 Improved						**Paddock 7A Unimproved**					
4700	22.7	700	2900	850	250	2200	28.1	50	1900	50	200
9200	24.5	1400	3750	3850	200	7200	25.1	350	6400	250	200
8600	21.6	1100	6300	850	350	5600	23.9	650	4050	400	500
7700	20.5	2750	3100	1400	450	4700	22.9	1300	2350	300	750
12200	20.3	4650	5100	1850	600	8300	21.7	2100	4950	750	500
Paddock 10B Improved											
6600	24.2	1000	4700	700	200						
11100	18.1	1900	8200	650	350						
7500	20.2	1600	4350	1350	200						
7900	18.1	2050	5150	550	150						
7200	19.5	2750	4100	300	50						

From Table 5 it will be seen that herbage production from stock camps even on control paddocks is high. This is probably partly the result of the concentration of animal excreta voided on these areas and partly because drainage from these hilltops is good and earth temperatures are sufficiently high in winter (see Fig. 5) for pastures to continue their growth. The highest production recorded was on a stock camp in paddock 10B which is a sunny face with improved pasture. The

stock camp in this area is a small ledge which receives the benefit of proportionately heavier stock concentrations than larger stock camps in other paddocks. Because of the general topography, climatic conditions are warmer and more conducive to growth on this sunny-face ledge than on a hilltop.

The average annual dry-matter production per acre of stock camps in the control paddocks (P1 and 7) was 12,400 lb in Paddock 1, 12,000 lb in Paddock 7A, and a higher production on the stock camp of the shady-face control paddock (7B) of 15,900 lb, probably because of greater stock concentration on its sunny hilltop. The stock camps on the sunny-face improved pasture produced 17,000 lb for Paddock 2, 15,900 lb for Paddock 3, and 20,300 lb for Paddock 10A. The shady-face improved-pasture stock camp (Paddock 10B) averaged 18,500 lb dry matter per acre per annum.

Production, particularly of grass, was much lower from the hillsides than from the stock camps, the control paddocks (1 and 7A) producing 4,900 lb and 5,600 lb of dry matter per acre respectively. Production from the shady-face control-paddock hillsides was 5,900 lb; these hillsides producing more during the summer months than the sunny faces because they did not dry out to the same extent. On the other hand, winter production was slightly lower.

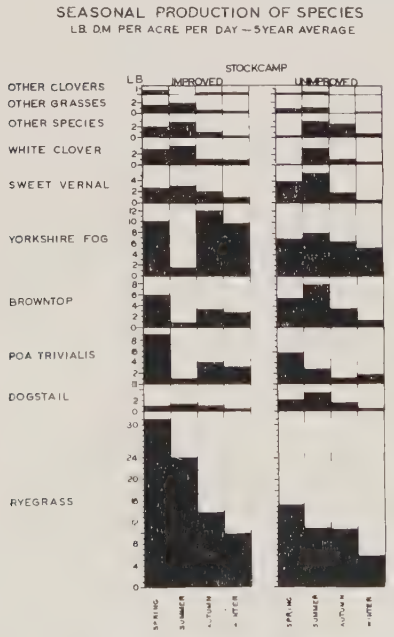

Fig. 14

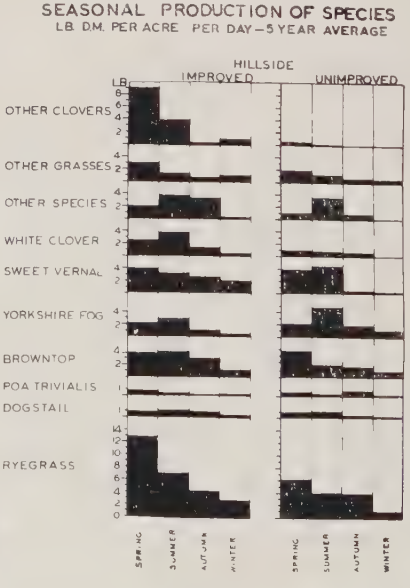

Fig. 15

Fig. 14.—Seasonal production of species in lb dry matter per acre per day. 5 year average from improved and unimproved stock camps.

Fig. 15. Seasonal production of species in lb dry matter per acre per day. 5 year average from improved and unimproved hillsides.

On the sunny-face improved hillsides, Paddock 2 averaged 8,300 lb; Paddock 3, 8,500 lb, and 10A, 9,300 lb. The shady-face improved hillsides (Paddock 10B) averaged 8,100 lb.

It can be seen from the herbage analyses that ryegrass increased markedly in the improved pastures on both stock camps and hillsides. There has also been an increase of ryegrass in the control paddocks, owing to heavier and more uniform stocking after the area was subdivided.

Clover content has not increased in the control paddock (1) but in the unimproved paddocks (7A and 7B) summer spelling, to encourage the reseeding of existing clovers, has increased slightly the clover content of the herbage. On the improved pastures, there was, however, a marked increase in all clovers.

Seasonal Herbage Production

Figs. 14 and 15 show the average seasonal production of species from stock camps and hillsides on both sunny and shady hillsides on unimproved and improved pastures for the five-year period. Fig. 16 shows the annual variation in pasture production and Fig. 17 shows the seasonal differences over the period on hillsides and stock camps.

It can be seen that ryegrass increased more on the stock camps of the improved paddocks than on the unimproved. Browntop and crested

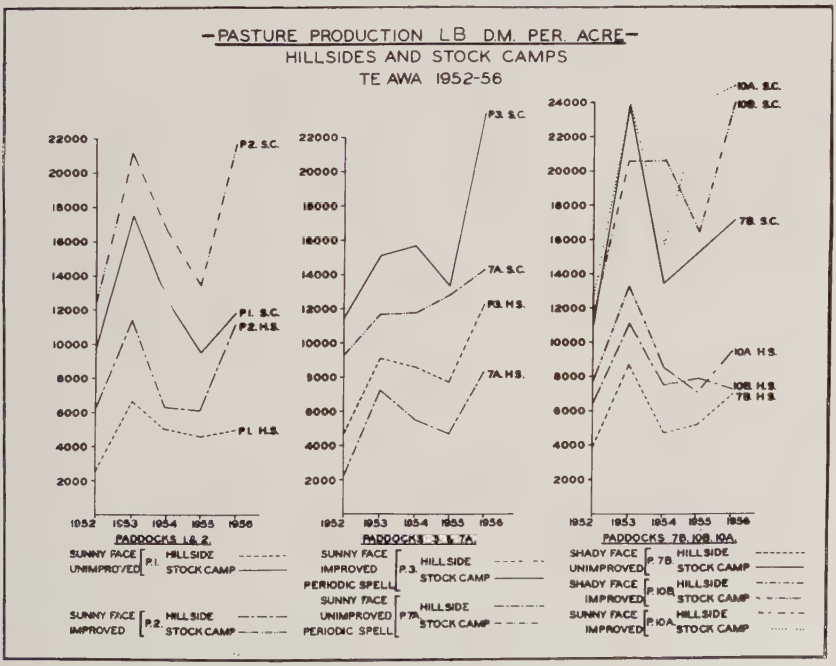

Fig. 16.—Pasture production in lb dry matter per acre from hillsides and stock camps for the period 1952-56.

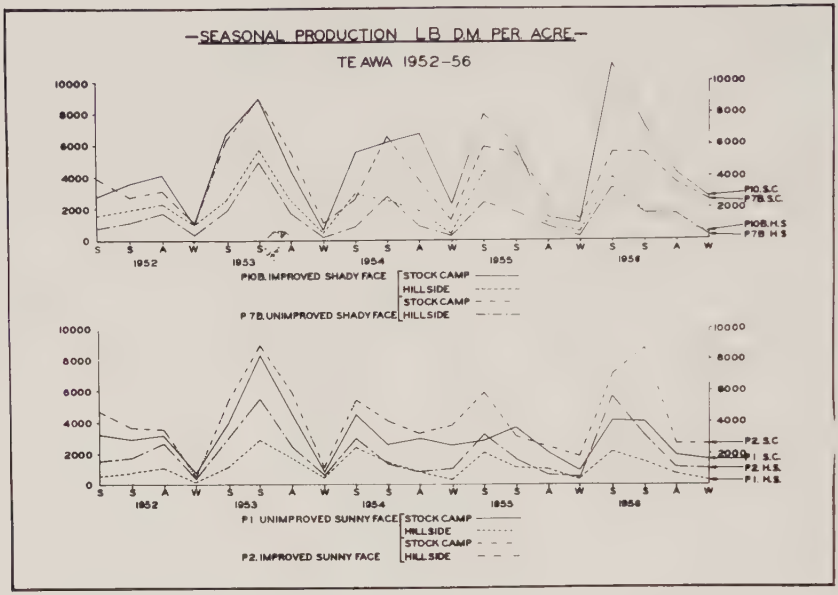

Fig. 17.—Seasonal production in lb dry matter per acre for the years 1952-56 from stock camps and hillsides on improved and unimproved sunny and shady face pastures.

dogstail decreased, while Yorkshire fog and *Poa trivialis* increased with the rise in fertility. There has been a marked increase in spring production of white clover and other clovers on the improved stock camps. In the unimproved paddock stock camps, suckling clover still produces some summer herbage but on the improved pastures this species was suppressed.

On the hillsides, the improved pastures have shown a large increase in ryegrass, browntop has remained much the same as in the unimproved paddocks in the spring months, but, in summer and autumn, browntop production increased on the improved hillsides. There has been a large increase from "other clovers" on the improved hillsides, particularly in the spring and summer, the species concerned being mainly subterranean clover and lotus major with some Montgomery red clover.

Protein Content of Herbage

Seasonal analyses for crude protein of the herbage from frame cuts were carried out for the years 1952-54, but in 1955 and 1956 bulked annual samples only were analysed.

It will be seen from Table 6 that there has been a progressive improvement in protein content on the unimproved sunny paddocks, and then only on the hillsides. Very low figures are shown in 1952, viz. 11.7%, but, by 1956, it nearly equalled that of the improved pasture (18.1%).

TABLE 6. SEASONAL AND ANNUAL AVERAGE CRUDE PROTEIN PER CENT 1952–56

Year	Site	Control Sunny Face 1 and 7A					Improved Pasture Sunny Face. 2, 3 and 10					Control Shady Face 7B					Improved Shady Face 10B				
		Spring	Summer	Autumn	Winter	Average	Spring	Summer	Autumn	Winter	Average	Spring	Summer	Autumn	Winter	Average	Spring	Summer	Autumn	Winter	Average
1952	Stock-camp	18.2	16.9	15.1	22.5	17.1	18.3	17.3	21.0	24.7	19.4	19.6	15.0	21.4	18.8	18.9	18.7	17.3	20.1	24.6	19.4
	Hill-side	12.5	12.4	10.5	15.9	11.7	16.2	15.9	17.5	22.0	16.9	15.9	15.8	15.6	13.9	15.6	20.1	18.2	19.5	21.4	19.5
1953	Stock-camp	19.1	17.3	14.8	21.9	16.9	20.0	17.1	20.8	22.6	19.6	18.9	19.4	23.9	21.3	20.5	19.3	19.2	21.3	22.4	19.8
	Hill-side	16.7	14.7	14.1	14.7	14.3	19.7	16.2	20.3	20.4	18.5	17.2	15.9	16.7	14.3	16.3	18.9	17.1	20.1	22.3	18.8
1954	Stock-camp	19.6	16.2	17.0	20.2	17.9	19.4	16.4	20.3	22.9	19.5	18.6	16.1	21.3	26.2	21.0	19.2	17.6	18.2	19.7	18.4
	Hill-side	15.8	14.7	16.6	17.6	15.8	18.8	17.2	16.9	19.6	18.0	16.2	15.1	16.1	17.1	15.6	19.5	16.0	19.1	21.3	18.4
1955	Stock-camp					16.8					21.6					20.7					18.4
	Hill-side					16.5					19.5					16.5					19.6
1956	Stock-camp					17.9					19.2					18.8					16.8
	Hill-side					18.1					20.0					15.9					18.8
3-yr Seasonal Ave.	Stock-camp	19.0	16.8	15.6	21.5	17.3	19.2	16.9	20.7	23.4	19.9	19.0	16.8	22.2	22.1	20.0	19.1	18.0	19.9	22.2	18.6
	Hill-side	15.0	13.9	13.8	16.1	15.3	18.2	16.4	18.2	20.7	18.6	16.4	15.6	16.1	15.1	16.0	19.5	17.1	19.6	21.7	19.0

Pasture on the oversown and topdressed sunny faces has also improved in quality, there being a gradual increase in protein content over the period. Herbage from the unimproved shady-face hillside was higher in protein content in 1952 than that from the unimproved sunny hillside and remained at much the same level over the five-year period. It is probable that this was brought about by the shady-face hillsides remaining green over most of the summer, thus retaining fresh feed rather than dry stalk and seedhead. On the sunny faces, grasses go to seed early in the spring unless heavily grazed at this time. There is usually a carry-over of dead stalk and seedhead for a considerable period into the winter.

The improved shady hillsides follow a similar trend to the unimproved shady hillsides. Crude-protein content has remained much the same over the period. There has been little change in crude-protein content of grass produced on stock camps; the annual average remaining at a similar level for all five years on both improved and unimproved pastures.

Seasonal trends on the improved sunny hillsides show highest protein content during winter and the lowest in summer. On the unimproved sunny hillsides protein content was highest in winter and lowest in autumn. For both the improved and unimproved shady faces there is little difference between autumn and winter, but protein content was low in summer herbage.

Some high crude-protein percentages have been recorded, the highest being 27.1 in winter on the improved sunny-face stock camp. It is probable that the figures recorded are conservative, as the method of herbage sampling from frame enclosures tends to allow for some maturity in the pasture. Stock on the other hand were consuming short, quick-growing grass, which would undoubtedly have a higher crude-protein content than more mature herbage.

Tiller Density on Set-stocked and Rotationally Grazed Pastures

During the course of the experiment it was observed that rotationally grazed pastures did not have the winter productivity of set-stocked pastures. When carrying capacity was relatively low, about 2–3 ewes per acre, differences between the two systems of management were not marked. However, as stock numbers were increased, rotationally grazed pastures pugged more and some sleepy sickness was experienced. This disease indicated feed shortages under rotational grazing whilst set-stocked ewes at similar and heavier intensities were not affected.

In order to determine one of the factors influencing pasture production during the autumn and winter, tiller densities were measured on set-stocked and rotationally grazed pastures. Table 7 shows the tiller numbers from three paddock sites within each of two set-stocked and two rotationally grazed pastures. It is apparent from the table that there were many more tillers per square foot on the set-stocked areas.

In the rotationally grazed paddocks, stock tracks were bared off each winter, whereas in the set-stocked paddocks, the tracks retained a

TABLE 7. NUMBERS OF TILLERS PER SQ FT SET-STOCKED AND ROTATIONALLY GRAZED PASTURES, JULY 1956

Treatment	Paddock No.	Tillers per sq ft			
		Grasses	Clovers	Other Species	Total
Set-stocked					
Stock Camp	2	2,380	210	50	2,640
	3	2,290	340	290	2,920
	Average	2,335	275	170	2,780
Tracks	2	2,010	300	30	2,340
	3	1,850	390	—	2,240
	Average	1,930	345	15	2,290
Slopes	2	1,870	880	70	2,820
	3	3,460	240	50	3,750
	Average	2,665	560	60	3,285
Rotationally grazed					
Stock Camp	4	1,550	230	20	1,800
	14B	1,220	130	40	1,390
	Average	1,385	180	30	1,595
Tracks	4	280	—	—	280
	14B	470	40	—	510
	Average	375	20	—	395
Slopes	4	2,060	190	80	2,330
	14B	1,200	200	50	1,450
	Average	1,630	195	65	1,890

strong dense turf. Table 7 shows that there was more than four times the number of tillers on the tracks in the set-stocked paddocks than on the rotationally grazed paddocks. It was also observed that rotationally grazed sheep under a regular shift system became restless, apparently anticipating a shift even after an hour or two in the paddock. Every disturbance caused the flock to commence congregating at the gate of the paddock. This restlessness and mobbing pugged the pasture and

bared the tracks, which are highly fertile, being the flat ledges on which animals walk and void their dung and urine. Ryegrass dominates as on the stock camps, and both areas are highly productive. However, mobs of sheep milling round can bare these fertile areas very rapidly. Pasture recovery on such areas bared during autumn and winter is very slow and, during periods of heavy rainfall, rotationally grazed paddocks have been pugged to the extent that production has been seriously affected for about 3-4 months.

Another factor that has contributed to the openness of rotationally grazed paddocks was the periodical spelling of pastures, followed by rapid defoliation by a mob of sheep. During these spells grass tillers are drawn up through competition for light and hence the basal buds are effectively suppressed. This is most apparent during periods of rapid growth in the spring and the autumn. On the other hand continuously grazed pastures form a dense sward with many tillers, each producing a small amount, which in the aggregate produce more herbage than the relatively few but larger tillers in a rotationally grazed pasture.

Carrying Capacity and Stock Management

In order to restock the area with a uniform line of ewes, 404 2-tooth ewes (average live weight 105 lb) were brought on to the area in February 1951. The majority of these remained on their various paddocks until the end of January 1957 when they were sold. At this time they were rising 7-year-old. However, to make up the required sheep numbers in 1951, 54 4-tooth ewes were also included in the total flock. In 1957 these ewes were rising 8-year-old and went off the property in good condition.

As stock requirements were heavy following pasture improvement and as a small percentage of the flock died each year, extra ewes of different ages were added to the various flocks. Records were kept of the original animals over the six-year period, while data concerning ewes of other ages were kept separate. It was observed, however, that the average weight of these other ewes was similar to that of the original groups on the various treatments.

It is important to note that all lambs were taken off the area each January and hoggets were not carried, except in 1952 when 55 late-castrated lambs were retained. These animals were disposed of in 1953 as fat 2-tooth wethers; only one died during the year.

A summary of the overall carrying for the 130-acre area is shown on p. 519.

The 50-acre paddock which had been under the owner's management since 1946, was in January 1955 taken over for experimental purposes and stocked with 200 ewes. An additional 25 ewes were added to this area in 1957, to give a carrying capacity of 4.5 ewes per acre. This increased the total flock to 825 ewes on the 180 acres now under experimental control.

With the rapid improvement in pastures it was found necessary to increase the number of cattle carried on the area, particularly up to

1953 difficulty being experienced in procuring enough ewes, and thus ewe carrying was comparatively low (3.6 per acre). In 1954 when ewe numbers were increased to 4.6 per acre, a herd of 25 dry cattle was carried and this number remained static for the next three years although a further slight increase in ewes was made. Cattle numbers were not increased when the 50-acre paddock was taken over in 1955.

	Stock carried on 130-acre area	ewes/acre
1947	Estimated 195 ewes + cattle	1.5
1948	Actual 209 ewes + cattle	1.6
1949	Actual 263 ewes + cattle	2.0
1950	Actual 266 ewes + cattle	2.0
1951	Actual 458 ewes + cattle	3.5
1952	Actual 464 + 55 wethers + cattle	3.6
1953	Actual 464 + 55 wethers + cattle	3.6
1954	Actual 586 + 25 cattle	4.5
1955	Actual 600 + 25 cattle	4.6
1956	Actual 600 + 25 cattle	4.6
1957	Actual 600 + 25 cattle	4.6

It will be seen that in the early stages of improvement varying numbers of cattle were carried in order to graze off rough unpalatable grass and weeds. As the pasture became more productive and as ewe numbers increased, little difficulty was experienced in controlling surplus feed with a smaller proportion of cattle. The usual method of cattle management was to graze them as a mob during periods of surplus growth on areas requiring additional control, and spread them on the various paddocks during the winter months. This largely overcame any tendency to pug gateways and other camping areas in wet weather.

Although cattle were amply fed in spring and summer, they were on short rations in winter. In spite of this, all cattle when taken off the area were in excellent condition.

The stock carried on the various paddocks, expressed as ewe equivalents, is shown in Table 8 for the years 1952-56. These figures do not include any grazing by the lambs. In all cases the rate of stocking for each year was determined in July-August after considering the feed available and the condition of the ewes.

On the set-stocked areas ewes were carried continuously. It was necessary, however, to move these each month for weighing, and on other occasions for shearing, crutching, dagging, and foot-rotting. The rotationally grazed ewes were shifted on Monday, Wednesday, and Friday each week, giving an interval of approximately 2½ days on each paddock and a 20-day spell between grazings. In periods of shortage during July and August, shady-face paddocks were occasionally grazed for shorter periods according to the pasture available.

The figures for carrying capacity of the various paddocks in Table 8 are actual ewe-days grazed. The data take into account deaths of ewes throughout the year and in addition ewes that have been grazed

TABLE 8. STOCK CARRIED 1951–57

Paddock No.	Area Acres	Ewes per Acre							Ewe Days + Cattle as Ewe Equivalent*						
		1951	1952	1953	1954	1955	1956	1957	1951	1952	1953	1954	1955	1956	1957
1	10	2.9	3.3	3.0	3.0	3.0	3.0	2.4	2.9	3.4	3.6	3.5	3.5	3.6	2.9
2	10	4.0	4.5	5.0	5.7	5.5	5.5	4.5	4.5	4.7	5.6	6.0	5.5	6.3	5.0
3	10	3.1	2.9	4.0	5.7	5.5	5.5	5.5	4.9	3.5	5.1	5.9	6.0	5.7	6.4
4A	5.3	3.2	3.9	3.6	4.6	6.1	2.7	3.9	4.0	4.0	4.2	7.0	6.1	3.0	4.5
4B	4.7	4.8	5.8	5.4	4.0				5.0	6.2	6.3	4.9			
5	3.4	2.7	2.7	3.5	4.1	4.1	4.2	4.1	2.7	3.2	3.8	5.0	4.6	5.6	4.8
6A	4.2	5.5	5.7	5.2	5.3	3.9	4.9	5.6	5.9	5.8	5.6	5.7	5.2	5.5	6.4
6B	5.2	3.6	3.9	3.4	5.4				3.6	3.0	5.1	5.5			
7A	3.3	3.0	2.2	2.3	3.5	3.6	4.2	3.7	5.4	2.2	4.5	5.8	4.4	5.8	4.2
7B	3.3	3.0	3.6	2.8	3.5	3.6	3.6	3.2	5.3	3.6	3.4	4.1	4.3	3.6	4.8
8A	5.4	3.1	4.2	4.7	5.6	4.8	5.2	5.2	3.4	4.3	5.8	6.5	6.0	6.1	6.0
8B	5.2	2.9	3.8	5.3	3.5	4.4	4.4	5.4	3.1	4.2	5.9	4.9	4.9	5.0	6.1
9A	5.6	3.6	3.6	4.5	4.3	4.4	3.1	4.1	4.1	3.7	5.5	6.2	7.1	4.4	5.0
10A	5.0	2.5	3.1	2.3	2.2				2.8	3.8	4.0	4.2			
9B	4.4	4.0	4.1	4.0	3.9	3.4	2.9	5.8	4.0	4.2	4.3	4.2	6.4	3.7	6.6
10B	5.0	2.2	3.3	2.6	3.7				2.2	4.0	3.4	4.1			
11A	3.4	4.9	5.6	5.6	5.5	4.2	6.1	6.3	5.1	5.8	6.3	5.5	6.1	7.0	7.2
12A	3.8	4.5	5.5	4.4	4.8				4.8	6.7	4.6	5.5			
11B	6.6	2.6	3.6	5.2	2.8	4.3	5.1	4.1	3.1	4.5	5.5	2.4	5.4	6.4	5.0
12B	6.2	3.2	2.7	2.7	3.0				3.8	3.2	4.6	3.7			
13A	4.9	3.6	4.2	4.5	4.9	3.2	5.6	4.1	3.7	5.1	4.9	5.4	4.4	6.1	4.6
14A	6.1	3.0	2.9	3.7	3.7				3.4	2.9	5.8	4.8			
13B	5.1	3.8	3.5	3.2	5.5	4.2	6.7	4.9	3.9	3.7	3.3	6.9	5.4	7.2	5.5
14B	3.9	3.6	3.5	4.4	6.5				3.6	4.0	5.4	6.5			
50 acres	50	—	—	—	—	4.0	4.0	4.5	–	—	—	—	4.6	4.8	5.1
Average		3.5	3.8	4.0	4.4	4.2	4.5	4.5	4.0	4.1	4.8	5.2	5.2	5.2	5.3
No. 1 Rotation	40	3.8	4.3	4.5	4.6	4.1	4.6	4.9	4.1	4.4	5.3	5.6	5.7	5.4	5.6
No. 2 Rotation	40	3.6	3.9	4.2	4.6				3.9	4.5	5.0	5.1			

* 1 Cattle beast equivalent to 5 ewes.

on the area for short periods, prior to culling, and stocking up each February. It is apparent that where heavy set-stocking has been practised, the need for cattle to consume surplus pasture has diminished. In practice, it was found that these paddocks required only a light grazing with cattle during the summer months. The rotational grazed pastures on the other hand, tended to grow away from the ewes in the spring and summer, and required more control by cattle. In order to retain a proportion of the rotationally grazed paddocks in good sheep pasture, one or two paddocks were shut up for reseeding of clovers, over the late spring and summer period each year. Table 8 shows the heavy cattle grazing necessary to clean up roughage accumulated on those paddocks during spells. High cattle figures are also shown where concentrated grazing by cattle was practised during summer to clean up weed growth in Paddock 12A and 14A, and 14B in 1955 and 1956, the weeds being in this instance largely toetoe which is consumed only under heavy cattle grazing. Sheep grazing days have been similarly increased when a flock has been grazed on spelled pastures for a longer period than normal to clean up roughage.

TREATMENT EFFECTS ON LIVE WEIGHTS OF EWES

All sheep were individually ear-tagged and weighed monthly or as near to the monthly interval as possible. Weighing dates were largely governed by weather conditions as it was found to be unsatisfactory to weigh ewes when wet. Fig. 18.

Fig. 18.—Central race to facilitate stock movement to weighing shed. Ewes being returned to their paddock after weighing.

The annual average ewe weights on the various paddocks are shown in Table 9. As live weight is a good index of ewe thrift, an effort was made to stock up the various treatments until a uniform

TABLE 9. ANNUAL AVERAGE LIVE WEIGHTS OF VARIOUS GROUPS OF EWES 1951–56

Year	Age	Paddocks											Flock Average
		1	2	3	4–9	5	7A	7B	10A	10B	11–14	50 acres	
1951	2-tooth	100	109	106	106	113	100	101	107	105	103	—	106
1952	4-tooth	116	127	123	115	131	116	111	121	120	112	—	117
1953	6-tooth	119	132	122	119	131	119	115	130	128	121	—	122
1954	Full mouth	119	129	127	122	137	129	120	136	130	125	—	125
1955	6 years	121	124	127	124	133	138	126	135	126	*	4th 120	125
1956	7 years	122	127	129	124	121	133	133	132	127	*	6th 130	127
6 yr. Av.		116	125	122	118	128	122	117	127	123	118		120

* Rotational flocks combined

weight was achieved. However, on the improved pastures, as soil fertility and pasture growth increased, so also did ewe weights, which would indicate that maximum carrying had not been reached. Table 9 shows that over a 6-year average the lenient-set-stocked improved paddocks (5 and 10A) produced the heaviest ewes. The heavily-set-stocked paddocks (2 and 3) although at 5½ ewes per acre over the last three years, still maintained a satisfactory average weight, the ewes being heavier than those on the rotational grazed areas. The sunny-face unimproved paddock (1 and 7A) showed different average live weights, largely because of the improvement of pasture in 7A brought about by spelling and encouraging the spread of clover by reseeding. Paddock 1 and the shady-face unimproved paddock (7B) were similar in ewe live-weight, both being lighter than the rotationally grazed groups.

The shady-face improved pasture (10B) group, although set-stocked at 4½ ewes per acre over the last 3 years of the trial, maintained high live weights, comparable with the set-stocked sunny-face group at 5½ ewes per acre.

There is no indication from the overall flock averages that increasing stock has seriously affected ewe live-weights.

Fig. 19 shows the average monthly live-weight for the various groups of ewes. There was a general rise in weight for all groups up to 1954 when they were "full mouth" or 4½ years old. A general decline is then seen for the remainder of the trial to a level similar to that when the ewes were 3½ years old. On most hill farms ewes are "cast for age" at 5 years of age, usually because of worn teeth. At Te Awa with improved pastures, ewes were held two years longer than normal and remained in excellent condition as can be seen by their live-weight graph.

Points arising from the live-weight differences are:

(1) The pastures that were oversown and topdressed and leniently-set-stocked produced the heaviest sheep of any of the treatments until 1955. After 1955 this grazing practice was discontinued and the areas stocked up to capacity.

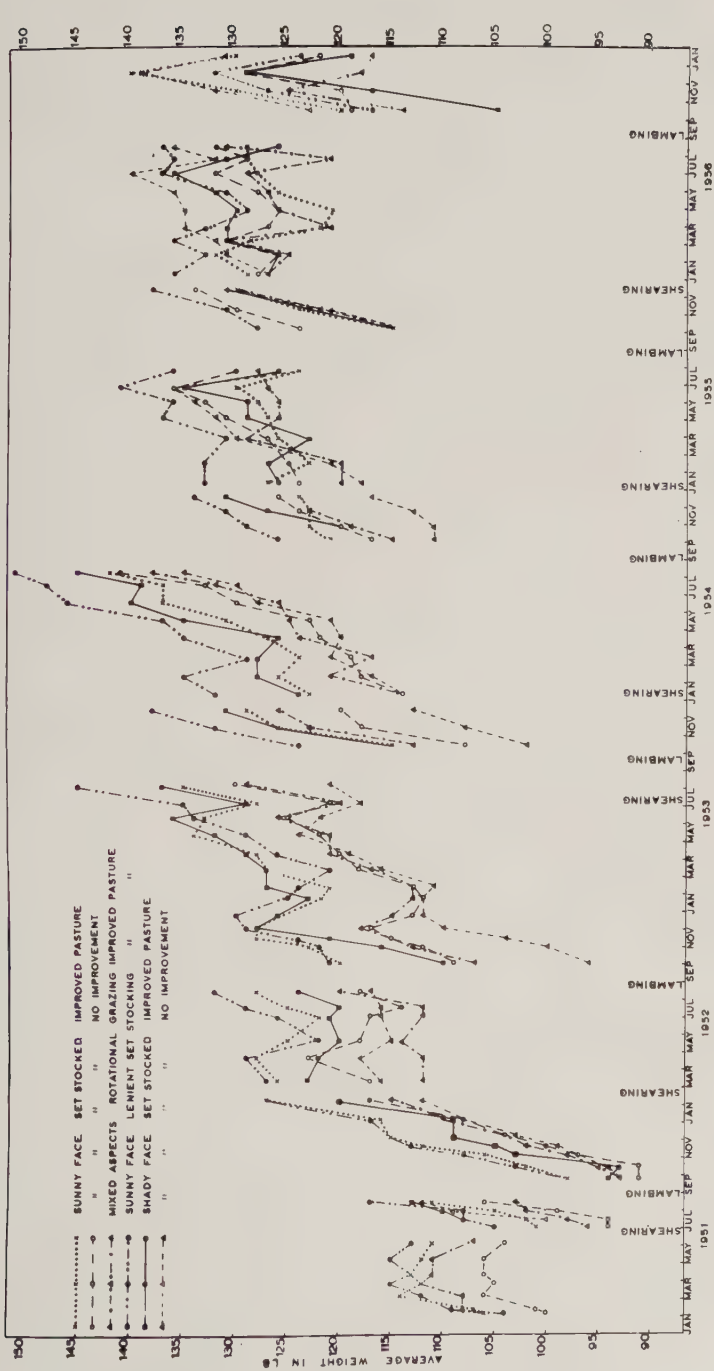

Fig. 19.—Average flock weights for the period January 1951-January 1957.

(2) On the heavy-set-stocked, improved, sunny-face areas (up to 5.5 ewes per acre), in spite of steadily increasing ewe numbers, body weights were maintained at a high level over most of the trial period. In 1954, ewe numbers were increased to 5.5 ewes per acre and ewe weights declined slightly, indicating that the sheep were competing for pasture, at the higher stocking rate during winter, more than at the lower rates of stocking.

(3) The ewes in the rotational grazing trial were little better in average live-weight, over the whole period from 1948 to 1954, than ewes set-stocked on *unimproved* pastures on sunny faces. When the rotationally grazed ewes were mob-stocked* from weaning to lambing, and then set-stocked from lambing to weaning, an improvement in live weight was recorded. There was, however, a lack of winter herbage when rotational grazing was practised too far into the winter. Subsequent trials indicated that a more dense and strongly tillered pasture resulted when the sheep were set-stocked from May rather than August.

(4) The unimproved shady faces produced the lightest ewes of all treatments up to 1955 when gradual increases in clover content brought about by heavier-than-normal stocking was reflected in heavier live weights.

(5) During 1955, all-the-year rotational grazing was discontinued and the two rotational grazed flocks combined. In order to consolidate the set-stocked areas and to facilitate stock movement on the mob-stocked areas, the set-stocked sheep on the shady-face improved paddock (10B) were moved to another shady-face paddock (8B) which had previously been under rotational grazing. The change from a tight dense turf to an open clover-deficient pasture in the autumn of 1955 resulted in a drop in live weight for this flock during the winter of that year and also in 1956.

(6) There has been a general depression in live weight of all groups during the January, February, and April-May periods. Roberts *et al.* (1956), in noting the autumn decline in live weight of their ewes, suggest that nutritional deficiencies in the herbage of the improved pastures are responsible for this check in thrift. At Te Awa there are indications that in some years the shady-face paddocks are not subject to this depression. Similar variations occur on the unimproved pastures but there is no consistency in the period of depression, or incidence of depressions in live weight.

It is possible that, following dry summers, rapidly growing autumn grass on improved hill country may contain a high proportion of nitrate, known to be present in large amounts in rapidly growing ryegrass in the autumn. Butler and Rae (1957) stated that the ingestion of nitrate at high levels can cause poisoning in sheep and cattle, and suggest that lower levels may also have an adverse effect on animal thrift.

* Mob stocking refers to the movement of stock from paddock to paddock as opposed to rotational grazing, where a regular shift is practised.

TUPPING AND LAMBING

In the years 1951-56, rams were put out during the period 18-21 March. Prior to 1951, Romney rams were used for the first month of tupping and then Southdown rams for the remainder. For the years 1951 to 1956, Romney rams only were used. For each small flock one ram was used while in the larger flocks the rate was one per 50 ewes. Rams were shifted to a new flock every two weeks to allow for possible ram sterility.

Lambing commenced about 20 August each year and continued through September and early October. As ewe numbers increased on the rotationally grazed areas, more and more trouble was experienced with mismothering of lambs when shifting mobs. Although the ewes were not driven from paddock to paddock in their rotation, but allowed to drift through, it was found that there was a tendency for all the ewes to congregate at the gate, at the slightest disturbance. In this way ewes frequently left their new-born lambs to graze fresh pasture. As a consequence many new-born lambs, twins particularly, were mismothered. On the other hand, there was very little mismothering on the set-stocked areas.

Table 10 shows the lambing percentage estimated on the number of ewes put to the ram and the number of lambs weaned. It will be seen that lambing percentages have been high throughout the period for hill-country sheep. In 1951, two-tooth ewes were grazed on the area and the lambing percentage was 92 for the whole flock. The years 1952 to 1955 were generally high although in 1956, when the flock was rising 7 years old, an outbreak of facial eczema was experienced on the set-stocked sunny-face pastures, and lambing percentages were lower in the sheep that had been affected.

From Table 10 it will be seen that, for the years 1951-55, ewes on the control paddocks had an average lambing percentage of 99. The comparable figures for the ewes on the heavy-set-stocked sunny faces were 104; improved shady faces 102; and rotational-grazed ewes 97. Generally speaking, over the whole period, except for 1956 when facial eczema caused ewe losses and consequent low lambing percentages, it can be stated that improved set-stocked pastures produced the most satisfactory lambing percentages. The lenient set-stocked improved pasture (10A and 5) produced the highest number of lambs (115%). However, in 1953 some ewes on one of these two paddocks (10A) were seriously affected by bearing trouble and as a result, a very low lambing percentage was recorded.

The rotational-grazed pastures produced a consistently low lambing percentage, mainly brought about by shifting stock during lambing with consequent mismothering.

In 1954, after six years of all-the-year rotation with two separate flocks of ewes, it was decided to set-stock one group from lambing to weaning, and to continue rotational grazing the other group. Lambing percentages for the continuously rotated flock were 4% lower than for the set-stocked (lambing to weaning) group.

TABLE 10. LAMBING % ESTIMATED ON NUMBER OF EWES PUT TO RAM AND OF LAMBS WEANED

Paddock No.	1951 2ths.			1952 4ths.			1953 6ths.			1954 Full Mouth			1955 6 yrs.				1956 7 yrs.			
	Ewes	Lambs	%	Ewes	Lambs	%	Ewes	Lambs	%	Ewes	Lambs	%		Ewes	Lambs	%	Ewes	Lambs	%	
1	30	22	73	30	30	100	30	27	90	30	26	87		30	33	110	30	31	103	
2	37	34	92	40	45	112	50	49	98	55	58	105		55	53	96	55	33	60	
3	38	42	111	39	45	115	44	45	104	55	56	102		55	57	103	55	46	84	
4–9	158	134	85	148	144	99	143	142	99	179	170	95	Rotational grazing flocks combined							
5	9	10	111	8	11	138	11	12	109	13	16	123		14	19	135	13	9	69	
7A	20	19	95	10	9	90	10	12	120	12	9	75		12	15	125	12	15	125	
7B				10	9	90	10	12	120	12	13	108		10	10	100	10	12	120	
10A	26	25	96	13	15	115	14	9	64	20	21	105	8A	21	34	162	27	31	115	
10B				13	15	115	16	16	100	19	19	100	8B	19	19	100	23	19	83	
11–14	140	135	96	139	146	105	136	142	104	184	168	91		384	387	101	375	386	103	
50 acres													4ths.	200	219	110	6ths. 200	215	107	
Total flock	458			450			464			579				800			800			
Total lambs		421			455			467			556				846			797		
Average lamb %			92			101			101			98				106				99.6

TABLE 11. AVERAGE DAILY GAIN IN LAMB WEIGHTS (LB) FOR THE LAST MONTHS PRIOR TO WEANING AND THE AVERAGE LAMB WEIGHTS (LB) AT WEANING FOR EACH GRAZING TREATMENT

Paddock		1951		1952		1953		1954		1955		1956		6 Year Mean
		Weaning Wt. 6.12.51	Daily Gain	Weaning Wt. 7.1.52	Daily Gain	Weaning Wt. 21.12.53	Daily Gain	Weaning Wt. 15.12.54	Daily Gain	Weaning Wt. 12.12.55	Daily Gain	Weaning Wt. 19.12.56	Daily Gain	
1	Control, sunny face	44.4	.39	62.2	.37	59.3	.39	61.5	.44	56.7	.41	63.1	.50	.42
2	Improved pasture, sunny face	52.0	.46	63.4	.38	61.1	.43	57.4	.40	65.3	.53	66.1	.53	.45
3	Improved pasture, sunny face	50.2	.43	Pad. Spelled		61.7	.44	60.1	.43	65.0	.54	65.3	.52	.47
4–9	Improved pasture, rotational grazing	41.3	.33	57.5	.32	57.6	.37	54.8	.37	Rotational flocks combined				.40
5	Improved pasture, lenient set-stocked, sunny face	52.9	.45	66.5	.42	66.8	.41	59.4	.43	60.4	.52	69.5	.52	.44
7A	Control, sunny face	37.4	.19	Pad. Spelled	—	61.5	.43	62.6	.45	58.9	.48	59.6	.46	.40
7B	Control, shady face	47.5	.41	58.5	.33	62.0	.43	63.6	.50	52.2	.38	66.8	.50	.42
10A	Improved pasture, lenient set-stocked, sunny face	47.2	.29	65.1	.41	66.0	.50	63.8	.50	58.8	.43	62.5	.43	.43
10B	Improved pasture, shady face	42.6	.40	65.1	.40	63.9	.47	64.4	.49	60.5	.45	58.6	.44	.44
11–14	Improved pasture, rotational grazing	43.5	.34	56.8	.32	59.6	.40	59.2	.42	60.2	.48	58.6	.40	.39
50 acres improved pasture, all aspects		—	—	—	—	—	—	—	—	57.7	.53	68.5	.48	.50

The average annual loss of lambs for the period under review was 12% of all lambs born, the largest proportions of these deaths occurring shortly after birth. Approximately 30% of these lambs died before or immediately after birth and 70% died after walking. McFarlane (1954) gives a death rate of approximately 15% of all lambs born in the Gisborne area.

Daily Gain in Lamb Weight

The mean weight of lambs at weaning and their daily gain in live weight during their first three months are shown in Table 11. The data in the table refer to groups of lambs of similar age selected each year for weighing (50 for rotational grazing groups, 30 for Paddocks 2 and 3, 20 for Paddock 1, 15 for 10A and 10B, and 8 for 7A and 7B). They are thus representative of growth rates and weaning weights of lambs born at the peak of the lambing season.

It will be seen that the weaning weights of the lambs on the control areas are consistently lower than on the oversown and topdressed heavy-set-stocked areas. On the other hand, the lenient-set-stocked improved pastures (P.5 and 10A) produced the heaviest lambs of all treatments. On the rotationally grazed treatments both the daily gain and the weaning weights were considerably poorer than on the improved set-stocked pastures and were also poorer than those from the unimproved pastures. When one of the continuously rotated flocks was set-stocked from lambing to weaning, the results almost equalled those of the heavy-set-stocked improved pastures, and indicated that an immediate improvement in daily gain and weaning weight was achieved from this set-stocking practice. This was also reflected in heavier ewe weights on these pastures than on the continuously rotated area.

It is believed that lamb thrift was adversely affected by the regular shifts with the resulting fluctuating planes of nutrition. On the other hand it can be stated that, on the Te Awa area, set stocking at heavy rates (5.5 ewes plus lambs per acre) produced strong, healthy lambs. Considering heavy set-stocking against lenient set-stocking on improved pastures, the difference in lamb weight from 3–4 ewes per acre is on the average, only about 1 lb more per lamb than from set-stocking at 5–5.5 ewes per acre. The overall gain is heavily in favour of high stocking in terms of lamb numbers, total lamb weight, and lamb wool weight per acre. It will also be seen in Table 11 that lamb weaning weights have not declined over the six-year period, although ewe carrying has increased markedly.

Lamb Fleece Weights

Each year lambs were weaned in late December at an average age of about four months, and usually before the ewes had been shorn. All ram lambs were taken off the property to be raised as flock rams on the flats, while the ewe lambs were mixed with those from the remainder of the estate and grazed separately on hill pasture. Because of the late shearing dates during most seasons, it was not possible to determine lamb fleece weights except for the 1954 season when shearing was completed at the beginning of January.

The figures recorded for 1954 and those for 1948-51 when shearing dates were earlier are compared as follows:

TABLE 12. MEAN FLEECE WEIGHTS OF LAMBS (lb)

	1954	1948-51
Set-stocked (no seed or fertiliser)	3.1	2.1
Set-stocked (seed and fertiliser)	3.3	2.3
Rotational grazed (seed and fertiliser)	2.6	2.2

It will be seen from Table 12 that lamb wool weights did not decline as carrying capacity increased. It is also apparent that set-stocked lambs produced more wool than those under rotational grazing.

EWE FLEECE WEIGHTS

It is normal practice in this district to shear between the months of October and January. However, on the Te Awa area, winter shearing was practised in 1951 and 1953. All fleeces were weighed individually and included bellies but not pieces or crutchings.

The mean weight of crutchings for the period when winter shearing was not practised was 1.5 lb per ewe. In 1951 and 1953 winter shearing replaced normal crutching prior to lambing.

It can be seen from Table 13 that shearing took place at irregular intervals. However, as records were kept over the whole period on one line of ewes, the average annual wool production can be calculated. As in the previous report, the heavy-set-stocked improved paddocks produced the heaviest wool weight per acre and per sheep. Ewes under rotational grazing produced less than set-stocked ewes and those on the control paddocks about the same figure as the rotational-grazed ewes. Sheep on the shady faces generally produced the lowest wool weights particularly on the unimproved shady faces.

STOCK HEALTH

From the commencement of the trial in August 1948, ewe deaths have averaged 4% annually. In 1952 a death rate of 0.6% was recorded with 4-tooth ewes, and in 1956 with an outbreak of facial eczema affecting some of the ewes on the sunny-face heavily stocked paddocks, losses rose to 6%. No particular treatment, with the above-mentioned exception, has shown significantly higher death rates than others. However, the lenient-set-stocked ewes on improved pasture produced a high incidence of bearing trouble (eversion of the vagina) particularly during the spring of 1953. Some sleepy sickness (pregnancy toxaemia) was experienced with 6- and 7-year-old ewes in the winter of 1955 where shady-face rotationally grazed pastures failed to produce sufficient feed to maintain aged ewes adequately. The main losses on

TABLE 13. AVERAGE FLEECE WEIGHT OF EWES 1951–57

Age	Shearing Date	Days Between Shearing	P.1	P.2	P.3	No. 1 Rotation P.4,6,8,9	P.5	P.7A	P.7B	P.10A	P.10B	No. 2 Rotation P.11–14	P.15 50 acres	Flock Average
2-tooths	1.7.51	248	8.3	8.4	8.5	8.6	8.5	8.5		8.6		8.4	—	8.5
4-tooths	18.2.52	232	6.8	7.4	7.2	6.8	7.2	6.7	5.7	6.8	6.5	6.2	—	6.7
6-tooths	18.1.53	335	7.9	8.4	8.2	7.7	8.9	7.4	6.5	8.0	7.7	7.4	—	7.8
6-tooths	17.7.53	181	6.7	6.6	6.0	6.0	6.6	6.2	6.3	6.7	6.9	6.4	—	6.4
Full-mouth	5.1.54	172	4.3	5.0	4.6	4.7	5.4	5.4	3.7	5.2	4.6	5.0	—	4.8
Rising 6-yr. old	12.1.55	372	9.5	9.7	10.3	9.3	10.5	10.6	9.1	9.7	9.7	10.5		9.9
Rising 7-yr. old	15.12.55	337	8.1	7.9	8.4	8.3*	8.9	9.3	8.1	9.0	8.4	8.3*	8.5	8.3
Rising 8-yr. old	11.1.57	393	8.9	9.9	9.2	9.8*	9.7	9.8	9.4	8.8	8.5	9.8*	11.6	9.8
Av. wool weight corrected to 365 days			10.0	10.5	10.4	10.2	10.9	10.6	9.5	10.5	10.1	10.3		10.4

* Two rotational grazing flocks combined.

the area have been through lambing troubles, bearing troubles, and milk fever. Some were lost through being cast and others through becoming bogged in slips and swampy areas.

Cattle losses have been light although, over a period of 9 years, 3 steers were lost in one paddock through tutu poisoning. This tutu has since been sprayed with 2,4,5-T, with moderate success.

Foot Rot

In the early stages of the trial considerable trouble was experienced with foot rot. Repeated treatment involving putting the sheep through a bath of copper sulphate, and frequent trimming and paring have greatly reduced the trouble. There has, however, been a larger incidence of foot rot on the rotationally grazed areas, probably due to scald on the longer pastures and to the muddy condition of the gateways and tracks on the rotationally grazed paddocks in the winter. Although the spell between grazing each paddock was sufficiently long for the control of the foot-rot organisms, carriers in the flock perpetuate the complaint in spite of frequent attention to the feet.

DISCUSSION

Set-stocking

On the unimproved paddocks, ewes were set-stocked at the rate of three per acre throughout the period under review. It was considered unwise to increase this rate because of the apparent lack of pasture production during the winter months. The sheep-weight graph (Fig. 19) shows that in the years 1951-54, ewes on the control areas lost more weight than any other group. This was particularly so on the shady-face paddocks. As the pasture improved, however, there was an improvement in the live-weight of the ewes during the winter. Additional stock could have been carried on these areas during the spring and summer but the difference between spring and winter production was extreme, hence cattle were used to consume surplus summer feed, and ewe carrying capacity remained static. There is no doubt that an additional half ewe per acre could now be carried because of gradual pasture improvement through more intensive stocking and increased clover growth.

The heavy-set-stocked improved paddocks continued to produce heavy ewes and good-quality lambs. Wool weights were maintained in spite of increased stocking rates. Similarly, lamb weaning weights were as high at 5½ ewes per acre as they were when 2 ewes were grazed. Because of the continuous set-stocking programme, ewes were inclined to become overfat during the summer period on the improved pastures and more particularly on the lenient-set-stocked pastures. There was no opportunity to reduce their condition in order that they might be flushed prior to tupping. However, it can be seen that lambing percentages remained high except for 1956 when facial eczema caused a drop in the number of lambs born. Lenient set-stocking on improved pasture resulted in the heaviest ewes and lambs. However, the growth of surplus pasture only resulted in overfat sheep. This herbage could

have been used to carry additional ewes and thus produce more wool and more lambs. In order to control surplus growth, a higher proportion of cattle grazing was required on these paddocks.

In considering the economics of lenient set-stocking against heavy set-stocking on improved pasture, the balance is heavily in favour of high stocking rates in terms of lamb numbers and total lamb weight per acre. Similarly, wool production per acre is much higher on the heavily set-stocked areas, even though individual fleece weights may not be quite as high as those from sheep on the leniently set-stocked areas.

Although set-stocking at Te Awa appears to be the most satisfactory management system, it is nevertheless subject to some weaknesses from a stock and pasture point of view. Some of these factors are:

(1) Ewes are probably more subject to bearing trouble where stocking rates are insufficient to utilise completely all the feed produced during periods of rapid pasture growth.

(2) Ewes become too fat at certain times of the year.

(3) Troubles such as sleepy sickness and milk fever may be encountered where set-stocking at heavy rates has made it impracticable to fit pasture growth to animal requirements. Even with heavy stocking and full utilisation of pastures, the animal is subjected to periods of feed shortages and surpluses, although to date the heavy-set-stocked sheep have wintered satisfactorily.

(4) It is not possible under continuous set-stocking to set aside pastures for reserve feed to be used in times of summer drought or winter shortages, or to guard against outbreaks of facial eczema.

(5) Continuous close grazing tends to encourage undesirable weed growth such as bidibidi, toetoe, nut grass and rushes.

Rotational Grazing

In summarising rotational grazing as a management practice, it may be stated that apart from some initial difficulties in shifting two-tooth ewes in the first few months before they are accustomed to regular movement, little trouble was experienced with the actual rotation of the flocks of sheep on the area, particularly when the ewes are without lambs. The period from lambing to weaning has presented some problems with the lambs. Rotationally grazed ewes become so accustomed to shifts that they are in a state of constant unrest and are ready to move at the slightest disturbance. This is of little consequence when the lambs are a few days old and are able to travel. New-born lambs, however, are frequently left behind and mismothered. At Te Awa it has been observed that ewes have tended to drift quietly through to the next paddock while the sleeping lamb is left behind, or the weaker twin is unable to follow. Mismothering has been a constant worry on the rotationally grazed areas. Set-stocked ewes are on the other hand more settled, with mismothering at a minimum.

Continuous rotation throughout the year has for other reasons proved unsatisfactory for stock thrift. One of the main reasons for the failure of rotationally grazed pastures on hill country to support stock satisfactorily in the winter months is the suppression of grass tillers. Pastures grow quickly during the spring and autumn, and this rapid growth, coupled with the regular spells, results in a general shading of the base of the grass plants, which suppresses tillering. In periods of little growth, i.e. summer and winter, pastures are open and often fail to respond between grazing. On the other hand, the set-stocked pastures, being constantly more uniformly grazed at a low level, are better suited to maximum tillering, with the result that a dense pasture is produced with a large number of leaves per unit area.

Measurements of tiller density have shown that in spring the improved set-stocked pastures at Te Awa averaged 3,200 tillers per square foot, while a good sheep pasture on the Manawatu flats, consisting of dominant ryegrass averaged 1,800 tillers. In good quality ryegrass/white-clover dairy pasture, 720 tillers per square foot were recorded and on a short-rotation ryegrass pasture, which had opened up somewhat, tillers were as few as 150 per square foot (Dr. K. J. Mitchell, pers. comm.). This illustrates the point that improved hill pastures containing a variety of species and under constant grazing, can form a dense mat with continued production from the large number of tillers present. Even though the growth from each tiller is small, total production is more uniform than in pastures under rotational grazing.

During wet weather, rotationally grazed pastures become fouled and pugged through large numbers of animals being shifted regularly from paddock to paddock. Restless stock have been observed to congregate round gateways at the slightest disturbance, thus causing unnecessary pugging of a large area of the paddock, and resulting in bare tracks.

Over the whole trial period, ewe live-weights and wool weights were lower, and lamb thrift was not as satisfactory as under set-stocking. It was also observed that lambs scoured more on the rotational grazing than on the set-stocked blocks. This is probably due to fluctuating planes of nutrition causing general dietetic upsets. Ewes were similarly affected, particularly during periods of rapid pasture growth.

Under lowland conditions, experiments have shown that intermittently grazed paddocks produced more than set-stocked paddocks. Climate, altitude, aspect, and botanical differences all have a bearing on the matter. Set-stocked pastures are uniformly grazed over the whole paddock and stock quietly "rotate graze" within a paddock when set-stocked even at high rates.

In periods of shortages, it was found that rotationally grazed flocks over-bare the pastures and open up the sward. Growth at these periods is slow and there is insufficient recovery of the dominant slow-growing species to meet the needs of the flock. Similarly, in spring there is a tendency for spelled pastures to rush up to seed-head and thus reduce leaf growth.

It is of interest to record that Barnicoat (1957) working on wear in sheep's teeth at Te Awa, showed statistically significant results in favour of rotationally grazed ewes compared with set-stocked ewes.

Compromise Management

One of the aims has been to reach a high carrying capacity as a means of achieving full utilisation at a palatable stage of all the pasture grown on the area, but with every effort to fit pasture production to animal requirements. To achieve this end, neither of the two extreme management systems has proved entirely satisfactory. It was considered necessary therefore to compromise and select the most desirable features of both systems which, when combined, would cater more satisfactorily for both animal and pasture.

In 1954, after six years of continuous rotation of sheep, the two rotational flocks were combined and the two rotational blocks of paddocks were consolidated to implement new management proposals. As the major objection to rotational grazing appeared to be associated with movement of stock from lambing to weaning, it was decided to set-stock the ewes over this period. Similarly, as the chief objection to set-stocking appeared to be the lack of provision of pasture for periods of shortage, plus the inability to control ewe live-weights in the summer, and hence run into possible low lambing percentages, ewes were mob-stocked during the summer and autumn period.

Some difficulty was experienced in determining the most satisfactory date at which to set-stock the ewes following mob-stocking. In August 1954, the ewes were set-stocked after being rotated continuously in the previous year. Pasture recovery was slow and some difficulty was experienced with the lack of production on the shady-face paddocks. It was necessary to shift stock according to feed supply around the various paddocks. Some sleepy sickness was experienced because of food shortages. During autumn 1956, ewes were mobbed, and shifted from paddock to paddock until June and then set-stocked. Even at this period, soil conditions had become very wet, and the stocking rates of over 40 ewes per acre caused serious pugging during heavy rain.

It was observed that pasture growth following heavy grazing or mob-stocking in wet weather was seriously retarded, and some paddocks that had been grazed during heavy rain failed to carry the required number of stock when again spread out for lambing. The carry-over effect of this damage lasted for some three months following mob-stocking.

It is apparent that sheep should be set-stocked before the ground becomes saturated, in order that a dense turf may be encouraged before winter cold almost stops pasture growth during July and August.

In 1957 the flock was set-stocked at the end of May and the difficulties already described were overcome. Pastures became densely tillered over the winter period and pugging was reduced to a minimum.

Under this management system, it has been possible to utilise pastures in the following manner:

(1) Immediately following weaning the aim has been to reduce the ewes in condition in order that a satisfactory lambing percentage may be secured. At Te Awa, flushing has usually commenced about three weeks before the rams are put out and continued for about 7 weeks. Ruakura experiments (Wallace 1953) have shown that this practice ensures a high lambing percentage.

(2) To conserve feed for this purpose, entailed the shutting up of improved pastures during the summer months, usually in late December. The shady-face paddocks have proved most satisfactory for this purpose as they do not dry out to the same extent as the sunny faces and, where a dense clover stand has been established, spelling at this time serves a dual purpose, firstly as conserved pasture for flushing, and secondly, for reseeding the introduced clovers in order to build up a large reserve of hard seed in the soil.

(3) During the period from the end of tupping till two weeks before lambing started, the flock was restricted in grazing area in order to carry forward conserved pasture for winter feed. The ewes were rotated round the remaining paddocks and suitably rationed to conserve the declining pasture growth.

(4) July and August are the most difficult months because pasture growth almost completely ceases at this altitude of 1000 ft. Temperatures are somewhat lower than on the flats and shady faces are about 4°F colder than the sunny faces. At this time, pastures conserved during April and May were grazed to prevent any fall in plane of nutrition as lambing approached. It is at this period that any marked feed reduction produces sleepy sickness.

(5) While saved pastures are being grazed, the remaining paddocks are spelled and although growth is slow, there is a fresh bite available for the ewes when set-stocked for lambing.

(6) Ewes were mustered immediately prior to lambing about mid August and sorted for early and late lambers, the early-lambing ewes being grazed on the best paddocks and the late and dry ewes on the others.

The system appears to be satisfactory, although one or two minor difficulties have been encountered. In wet summers there is an embarrassing accumulation of roughage and surplus grass which is carried through to the autumn period. Long pastures at this time of the year suppress clover growth and inevitably result in open stemmy pastures during the winter with a consequent lowering of production. To date, no satisfactory solution has been found for this problem where it is impossible to cut hay because of the steepness of the country. Similarly, there is a question regarding autumn-saved pastures for winter feed. It has been observed that these paddocks carry the flock for a short period only and fail to make a satisfactory recovery until the spring is well advanced. This means that the spelled paddocks do not carry the maximum number of stock, and add to the burden of other pastures. Problems such as these require investigation to determine their relative worth as compared with continuous stocking.

Insects and Earthworms

As the pastures that had been oversown and topdressed increased in fertility and in stock carrying, it was observed that the turf changed in character considerably. Originally the pastures had a sod-bound appearance particularly on the sunny slopes. There was little evidence of earthworm activity, except on the stock camps, where transferred fertility had accumulated for many years. Most hill pastures in the unimproved state have this sod-bound appearance and one of the reasons why high cattle-to-sheep ratios are maintained, is in order that heavy hoof cultivation might break up the sod-bound turf.

Over the years at Te Awa there was a change in earthworm populations, following the increased productivity of the pastures. At Grasslands Division it was found that as fertility and stock carrying increased, so also did the earthworm population. Sears (1949) and Waters (1955) estimated that on heavily stocked pastures the weight of earthworms in the soil approximated the weight of stock carried on the surface. Earthworm data were also secured at Te Awa on unimproved pasture, and on heavily set-stocked improved pastures.

TABLE 14. INSECT AND EARTHWORM POPULATIONS, 1956 MEANS OF 30 × ⅓ CU FT COUNTS PER PADDOCK SITE

	Control. No seed or fertiliser. Set-stocked				Improved pasture. Heavy set-stocked				Average Weight of Earthworms	
	Hillside		Stock Camp		Hillside		Stock Camp			
	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.	Feb.	Aug.
No. of *Allolobophora calliginosa*	144	355	204	510	238	487	289	961	0.15g	0.17g
No. of *Lumbricus rubellus*	34	69	41	81	40	71	35	172	0.20g	0.38g
Total earthworms	178	424	245	591	278	558	324	1133		
S.E.'S ±	26	46	31	42	30	64	49	86		
No. of *Oxycanus* spp.	1	1	4	6	0	7	3	4		
No. of *Costelytra* spp.	0	35	0	7	10	26	0	2		

Table 14 shows a summary of the earthworm populations in 30 × ⅓ cu. ft soil samples from stock camps and hillsides, during the summer when earthworm activity is low and in spring when they are most active. From Table 14 it can be seen that there were two main species, namely *Allolobophora calliginosa* and *Lumbricus rubellus*. As was ob-

served by Sears at Grasslands, the large common earthworm, *L. rubellus* was more prevalent in areas of high fertility whilst the small casting worm *A. calliginosa* was more numerous in the lower-fertility areas. The overall average weight of *A. calliginosa* was 0.15 g in February and 0.17 g in August whereas the average weight of the *L. rubellus* was 0.20 g in February and 0.38 g in August.

It is apparent that pasture improvement has increased the earthworm populations on the hillsides as well as on the stock-camp areas. Expressed in terms of worm weight per acre in August, there were approximately $1\frac{1}{2}$ tons per acre on the stock camps in the improved paddocks and nearly $\frac{3}{4}$ ton per acre on the hillsides.

This large number of earthworms undoubtedly aids in the incorporation of animal dung into the soil and returns more available plant food in their castings. The numbers of grass grubs (*Costelytra* spp.) and subterranean caterpillars (*Oxycanus* spp.) were not large in the areas under examination. However, further counts from pastures that had been spelled over the summer period showed an average of 24 grass grubs per cubic foot. It was also observed that on hillsides infestations were patchy.

Weed Control

In 1948, when the area was subdivided, there was a considerable amount of manuka, particularly on the shady slopes. During that year all heavy scrub was cut and the small plants pulled. In subsequent years young manuka has been pulled three times. However, the incidence of reinfestation has been greatly reduced over the period.

It was observed that where mob-stocking of sheep at heavy rates was practised, manuka seedlings and small shrubs were severely defoliated during grazing, thus giving some measure of control. The chief source of trouble has been on bare slips where manuka seedlings have been able to establish through lack of competition from dense pasture and treading by stock. Since all slips have been oversown as soon after they occur as possible, and a dense clover sward established, there has been less trouble with manuka.

Other weeds that have required control measures have been ragwort, yellow lupin, toetoe, and stinking mayweed. It has been observed that as fertility increased, thistles also increased. The most troublesome has been winged thistle. Large areas of stock camp and hillsides have been covered with a dense stand of this weed each summer. There has also been much Californian thistle and Scotch thistle. On the wet shady face, marsh thistle has been troublesome. As a control measure, thistles were scythed in the first two years, but in later years they were successfully sprayed with 2,4-D, although counts of buried seed have shown that there were still large quantities of viable seed of these species in the soil. In September 1956, spraying experiments were carried out using a helicopter, with great success. At the same time as the thistles were sprayed, an attempt was made to control tutu with 2,4,5-T, with moderately successful results. Only a small recovery growth was ob-

served from the roots, which has been easily controlled by subsequent spraying with a portable pump. Attempts at controlling some small patches of hard fern with this hormone were unsuccessful.

Plant Introduction

In the previous report, details were given of a large number of species which were tested under hill pasture conditions at Te Awa. During the period 1951-57 only one legume, *Parochetus communis*, which was considered likely to be of value, was tested. Rooted plants were planted on a hillside in spring, 1953, both under free grazing, and under small protecting cages. All plants established satisfactorily but within two years the grazed plots showed no evidence of survival whereas under the protecting cages the species was still persisting. At the end of 1957, a further inspection revealed that even under protection the species had failed to survive, either through competition from the associated grasses or because climatic conditions were unsuitable for the growth of this tropical species. It was concluded that *Parochetus communis* is of no value as a leguminous plant on hill country at Te Awa.

Conclusions

1. Climatological records have shown that there are no serious climatic limitations to pasture growth at Te Awa. During the winter, earth temperatures at 4 in. drop as low as 42°F on the shady country but remain as high as 45°F on the sunny faces. This means that sunny hill faces are some 2 or 3 degrees warmer than on the fertile flats at Palmerston North, giving continued but low pasture production during the winter.

Rainfall for 1948-56 averaged 42.5 in. and was spread fairly uniformly throughout the year. The highest rainfall months were July and November.

2. Subdivision of paddocks into sunny and shady faces has resulted in a marked increase in carrying capacity on the shady-face areas and has greatly assisted in increasing overall carrying capacity. Shady-face paddocks which in 1948 carried very little stock, successfully carried 4.5 ewes continuously set-stocked throughout the year in 1954.

3. Satisfactory methods have been evolved for the improvement of pastures by oversowing with clovers and topdressing with phosphates. Oversowing with clovers on clover-deficient hill country proved to be a practical method of achieving pasture improvement and consequently increasing stock carrying. Large increases in ryegrass and clover content have been recorded over the 9-year period. Further studies concerning the introduction of grass species into hill pastures have shown that it is practicable with appropriate management to achieve a successful strike of grass species from surface sowing.

4. Fertiliser trials have demonstrated that phosphate is the major mineral deficiency at Te Awa and indicate that even better results would have been achieved with heavier applications.

5. The practice of further improving oversown pastures by encouraging natural reseeding has been carried out since 1949. Buried-seed studies have shown that large quantities of hard legume seed may be built up with appropriate summer spelling. This reservoir of hard seed serves as a source of legume seed supply for a long period. These summer spells have also served the dual purpose of providing flushing pasture for ewes prior to tupping, particularly on shady country where pastures do not dry out to the same extent as on sunny country.

6. Herbage production, following pasture improvement, has increased markedly on the oversown and topdressed pastures. There has been a greater spread of seasonal production from the increased clover growth and a higher soil-nitrogen status. Growth extends longer into the summer, commences earlier in the autumn, because of the increased ryegrass content in the sward, and continues longer into the winter.

Large differences in production were recorded between hillsides and stock camps. On the sunny faces, improved pastures produced an average of approximately 17,500 lb dry matter per acre on the stock camps, whereas the hillsides on the same paddocks produced approximately 8,500 lb. The unimproved sunny faces produced 5,000 lb on the hillsides and 12,000 lb on the stock camps.

The unimproved shady faces produced approximately 5,500 lb d.m. per acre on the hillsides and 15,500 lb on the stock camps compared with the improved shady face production of 8,000 on the hillsides and 18,000 lb on the stock camps. It is apparent that there has already been considerable improvement in pasture production with oversowing and topdressing but it is also clear that there is scope for even greater improvement on the hillsides when compared with stock camps.

Improved pasture production has brought about more than a 300% increase in stock carrying capacity since 1948. What the ultimate carrying capacity may be is a matter for future trial.

7. Although ewe carrying capacity has increased greatly on the improved paddocks, there has been no apparent loss in ewe production. Wool weights have remained heavy, and lamb weaning weights have remained as high as when only 1.5 to 2 ewes were carried. Similarly, ewe live-weights for aged ewes (7 and 8 years) in 1956 were maintained at a similar level to that of 4-tooth ewes in 1952 although stocking rates had increased greatly during the period.

Over the six-year period, the heaviest ewes were produced off the heavily set-stocked paddocks which had been oversown and topdressed. These heavily set-stocked improved paddocks, although stocked at the rate of 5.5 ewes per acre for the last three years, maintained a satisfactory ewe live-weight, the ewes being heavier than those on the rotationally grazed area.

8. Lambing percentages were relatively high over the trial period. The control paddocks average 99%, the set-stocked improved sunny-faced paddocks 104%, improved shady-face set-stocked paddocks 102%, and the rotationally grazed areas 97% for the five years under review.

9. Daily gain in lamb weights showed that on the rotationally grazed treatments, both the daily gain and the weaning weights were considerably poorer than on the set-stocked improved pastures and poorer than on the unimproved set-stocked paddocks.

Lenient set-stocking on improved pasture produced the heaviest lambs but, in overall per-acre production, the heavily set-stocked improved paddocks were greatly superior.

10. Lamb fleece weights were heavier on the heavily set-stocked improved pastures than on the rotationally grazed pastures. Ewe fleece weights followed a similar trend, with similar weights being recorded from ewes on the control treatments to those under rotational grazing. Sheep on the shady-face paddocks produced the lowest fleece weights, particularly on the unimproved shady faces.

11. Winter shearing at Te Awa increased total wool production and reduced the number of cast ewes on the area. The major difficulty encountered with the practice was the bogging and mismothering of lambs on the broken and eroded hillsides when ewes sought shelter at lambing time.

12. Animal health was satisfactory throughout the trial. Ewe losses averaged 4% over the period 1948-57. No particular treatment has shown higher death rates than others, although sleepy sickness was encountered during winter on the rotational pastures through pugging with large numbers of ewes per acre, while on the set-stocked sunny faces facial eczema accounted for some of the ewes lost in the summer of 1956 when the highest death rate was recorded, i.e. 6%; on the leniently set-stocked improved paddocks more bearing trouble was experienced than on other treatments.

Some foot rot has been evident in the flocks but is gradually being overcome by constant attention. A higher incidence of this trouble was recorded in the rotationally grazed ewes, probably brought about by scald from longer pastures than on the set-stocked areas.

13. Tiller density studies showed fewer tillers on rotationally grazed paddocks during winter than on set-stocked pastures. This has probably resulted in a more satisfactory ewe live-weight level on the set-stocked pastures.

14. The improved pastures have increased in earthworm populations when compared with the unimproved pastures. There were approximately $1\frac{1}{2}$ tons per acre of earthworms on the stock camps in the improved paddocks and nearly $\frac{3}{4}$ ton per acre on the hillsides in August 1956. The control paddocks on the other hand had approximately $\frac{3}{4}$ ton per acre on the stock camps and $\frac{1}{2}$ ton per acre on the hillsides. It is apparent that increased pasture production and carrying capacity have increased the earthworm population.

15. When comparing set-stocking and rotational grazing, several points arise in favour of both systems. Set-stocking has proved the most satisfactory system from an animal thrift point of view. Rotational grazing has not been as satisfactory in this direction. However,

the system does allow for versatility in pasture management which is not possible under set-stocking. Because of the difficulties associated with both continuous rotation and continuous set-stocking, it was decided to compromise and utilise the best features of both systems. It would appear from the trial that both pasture and animal requirements can be best suited by a compromise system of management (Fig. 20).

Fig. 20.—General view of the area from the 50-acre paddock.

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REFERENCES

Barnicoat, C. R. 1957: A Study in Wear on Sheep's Teeth. *N.Z. J. Sci. Tech. A38 (6):* 583-632.

Butler, G. W.; Rae, A. L. 1957: A Progress Report on a Ryegrass Strain Trial with Particular Reference to Hogget Ill Thrift and Facial Eczema. *Sheepfmg. annu. Massey Agric. Coll. 1957,* pp. 181-88.

Corkill, L. 1954: Function of Pedigree Strains of Pasture Plants. *Proc. 16th Conf. N.Z. Grassl. Ass.* pp. 64-74.

Halliday, D. J.; Sylvester, J. B. 1950: A Survey of the Response of Grass to Nitrogen Fertilisers. *Bull. Jeallots Hill Res. Stn. 9.*

Levy, E. B.; Madden, E. A. 1933: Point Method of Pasture Analysis. *N.Z. J. Agric. 46:* 267-79.

McFarlane, D. 1954: Results of a Survey of the Causes of Losses of Lambs on Hill Country. *Sheepfmg. annu. Massey Agric. Coll. 1954,* pp. 127-33.

Roberts, E. M.; Murray, P. F.; Barnicoat, C. R. 1956: Note on the Autumn Decline in Live Weights of Grazing Ewes. *N.Z. J. Sci. Tech. A37 (6):* 606-9.

Sears, P. D. 1949: Soil Fertility and Pasture Growth. *Sheepfmg. annu. Massey Agric. Coll. 1949,* pp. 1-19.

————1951: The Technique of Pasture Measurement. *N.Z. J. Sci. Tech. A33 (1):* 1-29.

Suckling, F. E. T. 1950: Strike of Oversown Grass and Clover Seed on Hill Pastures. *N.Z. J. Sci. Tech. A32 (2):* 1-9.

————1951: Recent Experiments on Surface Sowing. *Proc. 13th Conf. N.Z. Grassl. Ass.* pp. 119-27.

————1954: Pasture Management Trials on Unploughable Hill Country at Te Awa. *N.Z. J. Sci. Tech. A36 (3):* 237-73.

Wallace, L. R. 1953: Management of the Fat Lamb Flock. *Proc. Ruakura Fmrs' Conf.* pp. 55-63.

Waters, R. A. S. 1955: Number and Weights of Earthworms under a Highly Productive Pasture. *N.Z. J. Sci Tech. A36 (5):* 517-25.

APPENDIX

PLANTS REFERRED TO IN THIS PAPER

Common Name	*Botanical Name*
Bidibidi	*Acaena sanguisorbae*
Browntop	*Agrostis tenuis*
Californian thistle	*Cirsium arvense*
Catsear	*Hypochaeris radicata*
Chewings fescue	*Festuca rubra* var. *commutata*
Cocksfoot	*Dactylis glomerata*
Crested dogstail	*Cynosurus cristatus*
Cudweed	*Gnaphalium* spp.
Dandelion	*Taraxacum officinale*
Danthonia	*Danthonia* spp.
Dock	*Rumex obtusifolius*
Goose grass	*Bromus mollis*
Hair grass	*Vulpia* spp.
Hawkbit	*Leontodon hispidus*
Hawkweed	*Crepis capillaris*
Lotus major	*Lotus uliginosus*
Manuka	*Leptospermum scoparium*
Marsh thistle	*Cirsium palustre*
Moss	Bryophyta spp.
Mouse-eared chickweed	*Cerastium glomeratum*
Nut grass	*Carex* spp.
Paspalum	*Paspalum dilatatum*
Perennial ryegrass	*Lolium perenne*
———	*Poa annua*
———	*Poa pratensis*
———	*Poa trivialis*
Purging flax	*Linum catharticum*
Ragwort	*Senecio jacobaea*
Red clover	*Trifolium pratense*
Ribgrass	*Plantago lanceolata*
Rushes	*Juncus* spp.
Scotch thistle	*Cirsium lanceolatum*
Self-heal	*Prunella vulgaris*
Short-rotation ryegrass	*Lolium perenne* × *L. multiflorum*
Sorrel	*Rumex acetosa*
Stinking mayweed	*Anthemis cotula*
Subterranean clover	*Trifolium subterraneum*
Suckling clover	*Trifolium dubium*
Sweet vernal	*Anthoxanthum odoratum*
Toetoe	*Arundo conspicua*
Tutu	*Coriaria arborea*
Winged thistle	*Carduus tenuifolius*
White clover	*Trifolium repens*
Yellow lupin	*Lupinus arboreus*
Yorkshire fog	*Holcus lanatus*

FUNGAL LEAF-SPOT DISEASES OF COCKSFOOT (*Dactylis glomerata* L.) IN THE MANAWATU

III. EYESPOT CAUSED BY *Selenophoma donacis* var. *stomaticola* (Baueml.) Sprague et A. G. Johnson, AND SCALD CAUSED BY *Rhynchosporium orthosporum* Caldwell

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Summary

Selenophoma donacis var. *stomaticola* and *Rhynchosporium orthosporum* are recorded for the first time as causing leaf spot diseases of cocksfoot in New Zealand.

Disease symptoms, morphology, colony characteristics on media, and manner of spore germination are described.

Neither disease is of economic importance in the Manawatu.

Materials and Methods

Conidia of *Selenophoma donacis* var. *stomaticola* are produced in pycnidia located in the centre of older lesions. The pathogen was isolated by first examining infected leaves under a binocular microscope, gouging out pycnidia with a sterilised needle and transferring to drops of sterile water. Spores escaped from pycnidia to the water so forming a rich spore suspension. Using a sterilised platinum wire loop conidia were then streaked across plates of potato dextrose agar (P.D.A.)

Rhynchosporium orthosporum was readily isolated to agar media by streaking a suspension of conidia prepared from diseased leaves. Naturally infected leaves were rarely located with conidia present. Sporulation was encouraged by subjecting diseased leaves to high humidity in petri dishes held at 20°C for two days. A spore suspension was then prepared by lightly touching the conidial mass with a sterilised needle and agitating the needle tip in a drop of sterile water.

The methods adopted for proving pathogenicity of isolates, the study of morphology, colony characteristics on media, the effect of media pH on growth rate, and manner and rate of spore germination were the same as previously described (Latch and Wenham 1958, Wenham and Latch 1958).

Eyespot Caused by *Selenophoma donacis* var. *stomaticola*. (Baueml.) Sprague et A. G. Johnson

The Disease

Young lesions on leaf blades and sheaths are at first purple, but with maturity the borders darken and centres become dark cream. Small

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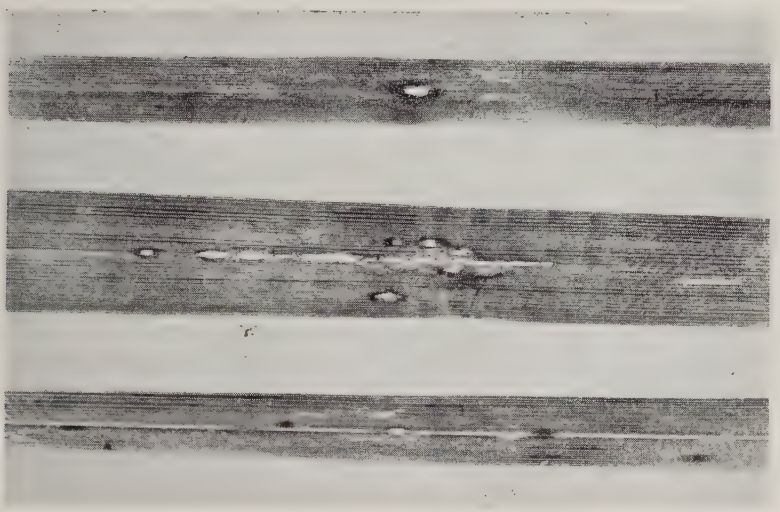

Fig. 1.—Lesions on cockfoot leaves caused by *S. donacis* var. *stomaticola*.

light-brown pycnidia are frequently present in the central cream-coloured areas, but rarely in large numbers (Fig. 1). Pycnidia occur more commonly on the lower than on the upper leaf surface. Tissues immediately surrounding lesions are usually pale yellow giving a halo effect to the eyespots. Where infection is severe the original lesions may spread and coalesce so that large patches of tissues are killed. In such areas pycnidia are usually present in larger numbers. Fascicles of conidiophores of *Scolecotrichum graminis* Fckl. have on occasions also been present on the larger lesions.

The pathogen attacks leaf blades, sheaths and seed stalks, and lesions have been found among the florets, suggesting the possibility of this fungus being seed-borne in cocksfoot. Allison (1954) has isolated the closely related species *Selenophoma bromigena* (Sacc.) Sprague et A. G. Johnson from seed of *Bromus inermis* Leyss.

Sprague (1950) and Sampson and Western (1954) refer to severe infection of cocksfoot by *S. donacis* var. *stomaticola* causing reduction in yield and quality of seed. In the Manawatu the disease was found at all months, being most prevalent in the spring, but never sufficiently severe as to affect appreciably production of foliage and seed.

THE PATHOGEN

Taxonomy

Fungi now included in the genus *Selenophoma* were originally regarded as species of *Septoria*. Passerini (1879) first described a sphaeropsidaceous species with non-septate, falcate spores, namely *Septoria donacis* Pass. on *Arundo donax* L. *Septoria oxyspora* Penz. et Sacc. was recorded in 1884 on *Arundo donax* L. and considered by Sprague and Johnson (1950) to be identical with *Septoria donacis* Pass,

Maire (1906) erected the genus *Selenophoma* to cover pycnidial species with hyaline, falcate spores. On the basis of Maire's description, Sprague and Johnson (1940) concluded that "certain fungi with non-septate, falcate spores borne in small globose pycnidia with coarse globose peridial cells were more logically assigned to *Selenophoma* Maire than to *Septoria* Fries."

The genus *Lunospora* erected by Frandsen (1943) has since been pronounced by Petrak (1947) to be identical with *Selenophoma* Maire. Thus Frandsen's type species *Lunospora oxyspora* (Penz. et Sacc.) Frandsen, also *Septoria oxyspora* Penz. et Sacc., and *Septoria donacis* Pass. are now considered synonyms of *S. donacis* (Pass.) Sprague et A. G. Johnson, with a recorded host range of over 40 grasses and cereals (Sprague and Johnson 1950).

Phyllosticta stomaticola Baueml. was included in *S. donacis* by Sprague and Johnson (1945) as *S. donacis* var. *stomaticola* Baueml., the variety differing from *S. donacis* in having shorter, narrower spores. This complex, with a recorded host range of over 30 grasses and cereals has been studied extensively in North America by Sprague and Johnson (1950), who have divided it into ten major groups. This differentiation into groups seems to be somewhat tentative as cross inoculations have been attempted to only a few of the recorded grass hosts and there are a considerable number of known hosts which have not been classified into this grouping. Group two contains "races" attacking *Dactylis glomerata* L. and *Koeleria cristata* (L.) Pers. The isolates from these two hosts are morphologically identical, produce a lavender tinted colony on culture media, and will cross inoculate.

Morphology

Pycnidia from lesions on stalks of field collections ranged in size from 20 to 75 μ by 25 to 95 μ and from leaves 50 to 115 μ by 65 to 140 μ. They were mostly dark brown, rarely black, prominently ostiolate, erumpent, and round to longitudinally elongate. Dimensions of pycnidia are recorded by Sprague (1950) as 40 to 150 μ by 40 to 110 μ, and by Shaw (1953) as 60 to 100 μ.

Conidia from naturally diseased leaves were falcate, non-septate and hyaline (Fig. 2). Uni-septate spores were occasionally collected from over-wintered material. Spore dimensions varied with the season at which collections were made. Spores from summer collections ranged from 14.9 to 21.5 μ by 1.7 to 3.3 μ (av. 16.9 by 2.7 μ), and from late-autumn collections 9.9 to 16.5 μ by 1.7 to 3.3 μ (av. 13.2 by 2.5 μ). Analysis of variance showed the difference in length between the two collections of spores to be significant ($p < 0.001$).

Cultural Features

It was found that this organism could not be cultured on artificial media for many generations without changing its colony characteristics. On P.D.A., colonies resulting from direct isolation to media from field-diseased material were generally circular in outline, slightly elevated, and wrinkled. Masses of conidia were formed directly on the mycelium.

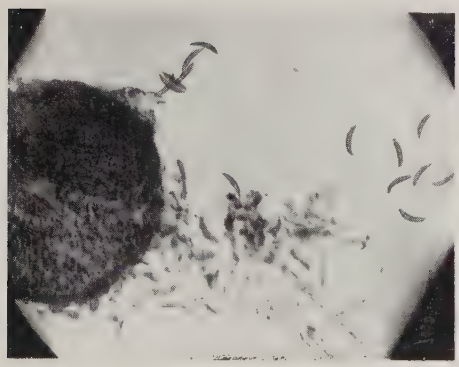

Fig. 2

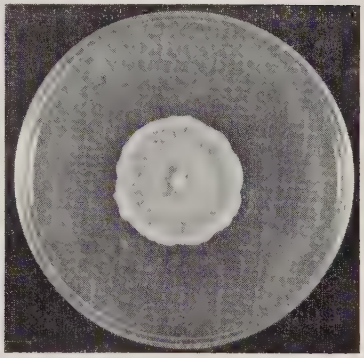

Fig. 3

Fig. 2.—Pycnidium and pycnidiospores of *S. donacis* var. *stomaticola* from cocksfoot.

Fig. 3.—Culture of *S. donacis* var. *stomaticola* on P.D.A. held at 24°c for 21 days. Colony diameter 37 mm.

Colonies were lavender in colour tending to pink in the centre, and when viewed from the reverse side were pink with purple edges. Subcultures from original isolates invariably yielded variant forms, and by the fourth generation there were few colonies resembling the original cultures.

In studying the effect of media type, temperature, and media pH on growth rate, the inoculum was one generation removed from the original spore suspension prepared from naturally diseased plants and had been cultured on P.D.A. for 14 days at 24°c. Growth was most rapid on P.D.A., tomato, oatmeal, and carrot agar, least rapid on soybean, prune, and water agar. Colonies on P.D.A. held at 24°c for 21 days averaged 37 mm in diameter (Fig. 3). On P.D.A. the fungus grew at temperatures between 5° and 28°c with optimum growth at 24°c. Growth rate dropped away sharply at temperatures above 24°c. At temperatures lower than 14°c there was abundant development of aerial mycelium. Growth occurred on P.D.A. at all pH values between 3.0 and 9.0, with optimum growth at approximately pH 5.9.

Spore Germination

In distilled water, spore germination was slow, a single terminal germ tube developing which remained straight and unbranched for periods up to 12 hours. On P.D.A. the pattern of spore germination was similar at all temperatures between 7° and 28°c. The spore first swells and one or two septa are formed. Within a few hours a germ tube develops from each end, branches, and becomes septate (Fig. 4). At 18 hours no difference could be detected between growth of spores at 20° and 24°c. Spores germinating at 28°c quickly formed germ tubes of several microns length but then almost ceased growth and remained at this stage during the following 24 hours. At both 20° and 24°c, sporulation was observed to have occurred after 38 hours, between 50 and 100 spores being produced in the central region of each thallus.

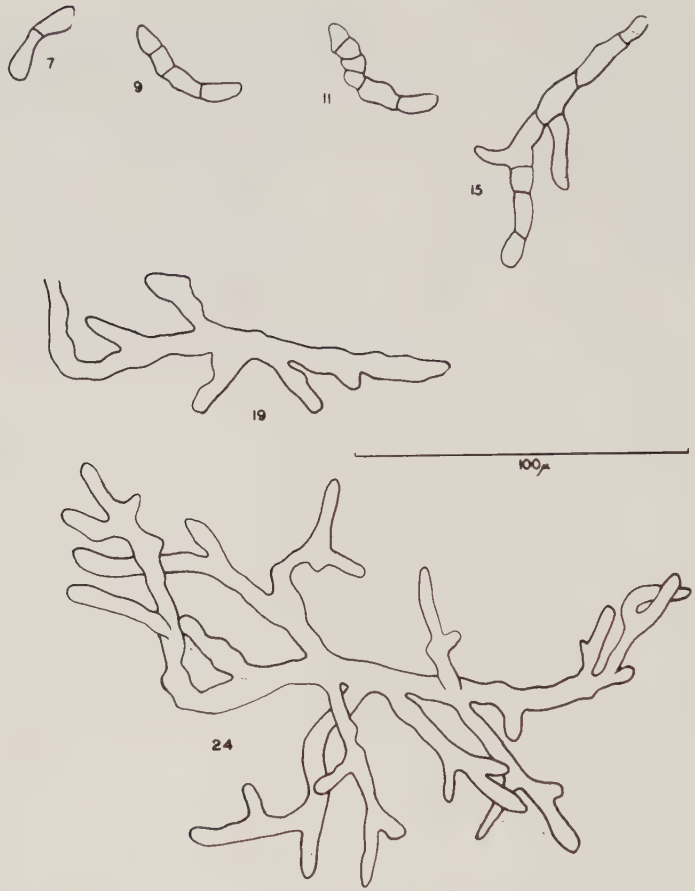

Fig. 4.—Stages of germination of a *S. donacis* var. *stomaticola* pycnidiospore on P.D.A. at 24°c over a 24-hour period.

Fig. 5.—Cocksfoot leaves showing field symptoms of scald disease.

SCALD CAUSED BY *Rhynchosporium orthosporum* Caldwell

THE DISEASE

First evidence of disease symptoms is the appearance of dark water-soaked patches one to three centimetres in length on either surface of leaves. These areas rapidly dry out and become light brown in colour with a distinctive dark-brown margin (Fig. 5). Lesions enlarge radially so that a series of concentric rings characterises older lesions. Owing to the presence of large dead "scalded" patches, which may be 20 cm in length, diseased leaves become severely wrinkled and folded.

Sprague (1950, 1955) has reported ten grasses as natural hosts of *Rhynchosporium orthosporum*, and to this list Meiners (1954) has added two further species. In New Zealand the disease has been located only on cocksfoot. In the Manawatu the disease was never very common during any month of the year. A few infected plants were located at all times but there was no particular period when the disease was more widespread and severe.

THE CAUSAL ORGANISM

Taxonomy

Caldwell (1931, 1937) recorded a distinct foliage disease of cocksfoot caused by a species of *Rhynchosporium* which he named *R. orthosporum* sp. nov. Symptoms were identical with those of barley scald disease caused by *R. secalis* (Oud.) Davis, but the two fungi would not cross inoculate. Further there were slight morphological differences in the shape of conidia, those of *R. orthosporum* being uniformly cylindrical whereas those of *R. secalis* are characterised by a beak. However, spore morphology is not always sufficiently distinct for separation of the two species. Sprague (1950) refers to a collection on *Agropyron subsecundum* (Lk.) Hitchc. from Utah which he hesitatingly assigned to *R. orthosporum*, although spores were of extremely variable size and shape, a few having a slight tendency towards the formation of obliquely hooked apices as in *R. secalis*.

Morphology

Intense production of conidia was induced by subjecting naturally diseased leaves to high humidity in petri dishes for two days at 24°C. Conidia were cylindrical, medianly uniseptate and formed in vast numbers on scant superficial hyphae in the central and most completely collapsed areas of lesions (Fig. 6). The dimensions of spores from naturally diseased leaves were 13.1 to 21.3 μ (av. 16.6 μ) by 2.5 to 5.0 μ (av. 3.6 μ). The dimensions of conidia of *R. orthosporum* are recorded by Sprague (1950) as 14.4 to 20 μ by 2.3 to 4.7 μ, and by Sampson and Western (1954) as 14 to 20 μ by 2 to 5 μ.

Cultural Features

The pathogen was slow growing but sporulated freely on all media tested. Growth was most rapid on oatmeal, P.D.A., cornmeal, and tomato agar, least rapid on soybean and carrot agar. Only on corn-

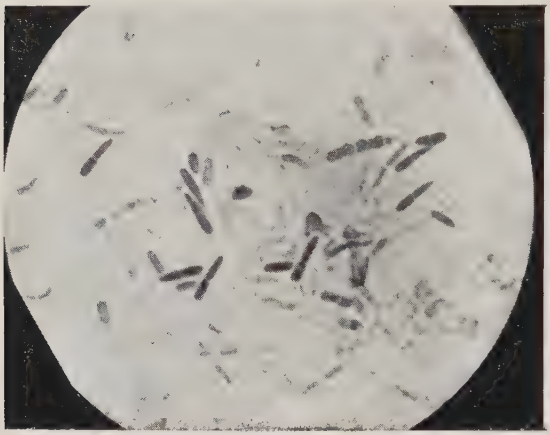

Fig. 6

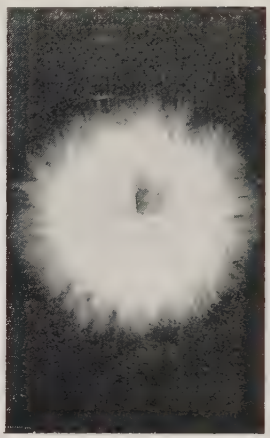

Fig. 7

Fig. 6.—Conidia of *R. orthosporum* from an oatmeal agar culture.

Fig. 7.—Colony of *R. orthosporum* on P.D.A. held at 17°C for 9 days. Colony diameter 9.5 mm.

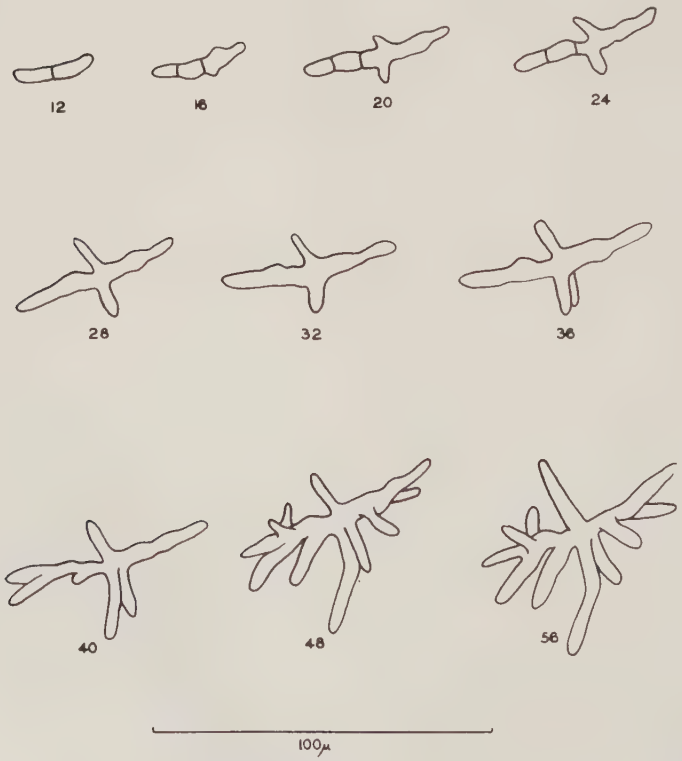

Fig. 8.—Stages in germination of a *R. orthosporum* conidium on P.D.A. at 19°C over a 56-hour period.

meal and oatmeal agar were conidia produced which closely resembled those from naturally infected cocksfoot leaves. Conidia from other media were one- to four-septate, and varied greatly in size and shape.

At nine days, colonies on P.D.A. held at 17°c were cream coloured with little aerial mycelium. Growth was in a uniformly radial manner and at the centre was formed a slimy, cream mound of irregularly shaped one- to three-septate conidia. The central region of colonies began to darken several days later and in the older colonies became dark brown. After several weeks the entire colony developed a very dark pigment so that the thallus appeared almost black.

Growth occurred on P.D.A. in the temperature range of 5° to 28°c, with optimum growth between 17° and 20°c. Nine-day-old colonies held at 17°c averaged 9.5 mm in diameter (Fig. 7). Colony morphology did not alter with temperature variation, and sporulation was abundant at all but extreme temperatures. Growth occurred on P.D.A. at pH values between 3.0 and 9.0. Optimum growth was at pH 5.9, colonies averaging 9.6 mm in diameter after 9 days at 17°c. The optimum temperature for spore germination on P.D.A. was in the vicinity of 19°c, and was characterised by development of a single terminal germ tube which quickly branched and became septate (Fig. 8).

REFERENCES

Allison, J. L. 1945: *Phytopathology 35:* 233-40.

Caldwell, R. M. 1931: *Phytopathology 21:* 109-10.

———1937: *J. agric. Res. 55:* 175-98.

Frandsen, N. O. 1943: *Medd. Vet-Hojsk. Plantepat. Afd., Kbh. 26.* 92 pp. (Abstr. in *Rev. appl. Mycol. 25:* 155-7.)

Latch, G. C. M.; Wenham, H. T. 1958: *N.Z. J. agric. Res. 1:* 182-8.

Maire, R. 1906: *Bul. Soc. bot. Fr. 53:* 180-215..

Meiners, J. P. 1954: *Plant Dis. Reptr. 38:* 277-8.

Passerini, G. 1879: *Atti Soc. Crittog. ital., Milano, 2:* 20-47.

Petrak, F. 1947: *Sydowia 1 (1-3):* 61-79. (Abstr. in *Rev. appl. Mycol. 27:* 99.)

Sampson, K.; Western, J. H. 1954: "Diseases of British Grasses and Herbage Legumes." C.U.P.

Shaw, D. E. 1953: *Proc. Linn. Soc. N.S.W. 78:* 151-9.

Sprague, R. 1950: "Diseases of Cereals and Grasses in North America". Ronald Press, New York.

———1955: *Plant Dis. Reptr. Suppl. 232:*

Sprague, R.; Johnson, A. G. 1940: *Mycologia 32:* 415.

———1945: *Ibid. 37:* 638-9.

———1950: *Ore. St. Monogr. Bot. 10.*

Wenham, H. T.; Latch, G. C. M. 1958: *N.Z. J. agric. Res. 1:* 800-8.

THE EFFECTS OF IODINE AND THYROXINE ADMINISTRATION ON THE ROMNEY CROSSBRED EWE

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(*Received for publication, 5 January 1959*)

Summary

Two trials designed to compare the effects of thyroxine implantations and iodine injected as potassium iodide and Neo-Hydriol (iodised poppy-seed oil) on the Romney ewe, showed that none of the treatments had any significant effect on fleece weight or grade. The following observations were made in the second trial:

Heart-rate measurements are highly repeatable, and are proportional to body weight, thus giving a reasonable indication of metabolic rate.

An April 60-mg thyroxine implant resulted in a slight but non-significant effect on heart rate, body weight, and wool growth. A 90-mg implant in November increased heart rate 66%, and decreased body weight 12 lb, but did not stimulate wool growth.

The two iodine treatments resulted in a highly significant effect on the thyroid glands, indicated by decreased cell heights and increased iodine contents, whereas thyroxine implantation slightly reduced cell height, but did not affect the iodine content.

Several observations point to the possibility of a borderline environmental iodine deficiency, which may account for the slight stimulation of wool growth by thyroxine treatment.

A daily dose equivalent to 0.7 mg of iodine injected as potassium iodide is adequate for a sheep's nutritional requirement, while an injection of 1 ml of Neo-Hydriol provides supplementary iodine for a considerable period.

Introduction

The stimulatory effect of thyroxine implantation on the wool growth of New Zealand sheep has been extremely variable (Hart 1954, 1955, 1957, 1958; Ross and Lewis 1958; Ross 1958; Coop and Clark 1958). Although several hypotheses have been put forward, the precise mechanisms involved are still obscure, and the reasons for this variability are not fully accounted for. Several factors including breed, age, nutrition, season in which the implant is made, and size of the implant, have been shown to affect the response, but as well as these there are obviously other important factors.

The function of the thyroid gland is to elaborate, store, and release the circulating thyroid hormones, thyroxine and tri-iodothyronine, which contain as an essential part of their structure the element iodine. Thus efficient thyroid function is dependent on an adequate iodine supply, and a full interpretation of thyroxine implantation responses must involve a knowledge of the iodine status of the sheep.

This paper reports the results of two trials aimed at elucidating the comparative effects of iodine and thyroxine on Romney ewes.

Review of Literature

As the literature on this topic is very voluminous only a brief review of some aspects of this problem is given. Iodine deficiency results in impaired thyroid function, manifested by compensatory hypertrophy and hyperplasia of the thyroid gland, which represent the efforts of the gland to maintain the required output of thyroid hormone. The deficiency may be absolute owing to a continual deficient iodine intake or it may be a relative effect conditioned by some factor which makes a critical iodine balance definitely negative, a fact substantiated by the observations of Orr and Leitch (1929) that the incidence of goitre varies in the same districts from time to time. This relative iodine deficiency may be precipitated by different conditioning factors; namely impaired adsorption or utilisation of iodine due to various causes, the most important of which is the repeated ingestion of goitrogens; *or* to an increased requirement of the element due to the demands of repeated pregnancies and lactation. However, whatever the cause, the end effect of persistent iodine deficiency is always thyroid enlargement or goitre, and many authorities believe that this is invariably accompanied by a small degree of hypothyroidism and by some derangements of bodily function (Salter 1940; Greer 1955; Underwood 1956). The extent and economic importance of a borderline iodine deficiency is not known. Minor degrees of iodine deficiency may pass unnoticed with only small effects on function and growth. Gross iodine deficiency in livestock is however characterised by irregularities in reproductive function associated in sheep primarily with the birth of dead, weak, and often partially woolled lambs, with acute swelling of the thyroid glands (Andrews *et al.* 1948; Orr and Leitch 1929; Hopkirk *et al.* 1930; Underwood 1956).

Before the introduction of iodised salt as a prophylactic measure, New Zealand with an average incidence of 31% in school children was notorious as a country in which serious endemic goitre occurred. In the Taieri Valley and Canterbury the incidence was 30% and 54% respectively (Hercus *et al.* 1925; Hercus and Roberts 1927).

Similarly in various areas of New Zealand, including some parts of Otago and most of Canterbury, there was a high incidence of enlarged lamb thyroids with low iodine contents (Mason 1933; Sykes 1934; Mason and Waters 1936; Waters 1938, 1939). Most of the work on the stimulation of wool growth by thyroxine implantation has been carried out in the Canterbury district.

The occurrence of congenital goitre in lambs in New Zealand is fairly widespread (Hopkirk *et al.* 1930; Sinclair and Andrews 1954; Cunningham 1955), a heavy incidence being frequently found for the first time on land with no previous history of goitre. In some flocks 50% of the lambs are lost, but treatment with iodine is generally beneficial (Cunningham 1951).

Seasonal Iodine Rhythm

The variable response to thyroxine implantation may be due to seasonal differences in the thyroid iodine content of ruminants which

are inversely related to thyroid weight changes. The literature on this seasonal rhythm (Orr and Leitch 1929; Hercus and Roberts 1927; Dawbarn and Farr 1932; Brody 1945; Henneman *et al.* 1955) is, however, contradictory and its relationship to New Zealand conditions is not clear. However, it does indicate that the iodine content may be high in late summer, and low in spring. This maximum and minimum coincides with the normal seasonal trends in wool growth in New Zealand (Story *et al.* 1956). This rhythm is probably due to a number of interrelated causes, all exhibiting seasonal fluctuations, the most important of which are probably seasonal changes in the demand for thyroid hormone, and varying iodine intakes. Thus the iodine content of cows' milk in England in winter has been shown to be higher and more variable than in summer, owing to the use of supplementary feeds rich in iodine (Young *et al.* 1936). Drought conditions in Australia result in a doubling of thyroid iodine content probably through a decreased demand for thyroid hormone (Dawbarn and Farr 1932), and Wright (1958) has demonstrated an inverse relationship between mean ambient temperature and thyroid ^{131}I absorption. It has been recently shown (Johnson and Butler 1957) that while some pasture species have a significantly higher iodine content in winter than in all other seasons, other species exhibit no seasonal differences, and a third group show significantly higher iodine contents in spring and summer than in autumn and winter. However, superimposed on the effects of variability of species and season on thyroid iodine content, the possible goitrogenic nature of some feeds, and the varying availability of iodine to sheep, must be considered.

Goitrogens

The ingestion of goitrogens cannot be excluded as a possible causal factor in the aetiology of goitre, especially in view of the recent appearance in Gisborne of serious congenital goitre when ewes were grazed continuously on thousand-headed kale towards the end of pregnancy (Sinclair and Andrews 1954). Such ewes not only produced goitrous lambs, but themselves showed evidence of impaired thyroid function (Wright and Sinclair 1958). Sinclair and Andrews (1954) demonstrated that the administration of large quantities of potassium iodide to pregnant ewes grazing thousand-headed kale markedly reduced the incidence of the disease in new-born lambs. This is however in apparent contradiction to the findings of Wright and Sinclair (1958) who have identified the goitrogen in thousand-headed kale as belonging to the thiouracil group of goitrogens, the effects of which are normally not reversible by the administration of iodine (Butler *et al.* 1956).

Iodine administration should also relieve a relative iodine deficiency induced by the thiocyanate type of goitrogen. Cyanogenetic white clover, in spite of a relatively high iodine content, was shown to produce a definite goitrogenic effect on guinea pigs, and the indications are that a similar effect is produced in sheep, although long periods of grazing the clover are probably necessary (Flux *et al.* 1956; Butler *et al.* 1957).

Iodine Requirement

As with all nutrients the requirement for dietary iodine will differ in different sheep and in the same sheep at different times. The absolute iodine requirement of sheep is not known with any degree of certainty for it is difficult to assess owing to the efficiency with which the thyroid re-traps iodine from the breakdown of iodine compounds in the body (Underwood 1956; Salter 1940).

Various estimates of the daily iodine requirement for a non-pregnant sheep of 110 lb body weight are: Mitchell and McClure 1937, minimum requirement 0.05 to 0.1 mg; Albritton 1954, normal requirement 0.15 mg. Pregnant ewes require 1.0 mg per day (Pearson *et al.* 1949; Albritton 1954). Orr and Leitch (1929) showed that sheep grazing on various pastures ingest 0.12 to 2.0 mg/day. However, figures for iodine requirement based on intake are not reliable as they take no account of availability. The desirability of giving an optimal amount of iodine as opposed to a minimum amount must however be emphasised.

In assessing the daily dose of 0.7 mg used in this work several factors were taken into account, viz, the increased requirements for pregnancy and lactation, the necessity for giving an adequate but not excessive amount, and the fact that the sheep were already receiving a certain amount of iodine in their diet.

Two methods of iodine prophylaxis have been used in this study. Firstly conventional potassium iodide therapy, and secondly Neo-Hydriol (May and Baker) a preparation of iodised esters of the fatty acids of poppy-seed oil, which when injected forms a "depot" from which iodine is available to the thyroid. Winikoff (1957) reported that 29 weeks after injecting intramuscularly 0.5 and 1.5 ml of Neo-Hydriol into humans, elevated protein-bound iodine (PBI) levels and depressed thyroid ^{131}I retention still persisted. Latterly it has been learned (Winikoff 1958, pers. comm.) that it was not until 19 months after the injection that all the 0.5 ml group regained PBI levels within the normal euthyroid range. At this stage, 2 of the 3 patients on the higher dose level still showed elevated PBI levels.

EXPERIMENTAL

Mature Romney Crossbred ewes of small stature were chosen for two reasons. Firstly if there was an iodine deficiency it would be manifested by a decreased growth rate, and accentuated by repeated pregnancies. Secondly the best responses with thyroxine have been obtained with mature ewes, in agreement with work on the stimulation of milk secretion in cows by thyroxine where the response was shown to increase with increasing age (Blaxter 1952).

Trial I was a general field trial carried out near Geraldine in south Canterbury in an area considered likely to be iodine deficient.

Trial II was an intensive study carried out at Invermay Research Station, which is situated at the head of the Taieri Plain about 10 miles west of Dunedin.

In both trials the ewes were run on ordinary pasture including the normal quantities of goitrogenic feeds. In Trial II, supplementary feed, in the form of hay, mangels, and turnips, was supplied in the late winter. For about a month during lambing the feed was poor, but for the rest of the trial period the ewes were grazing excellent pasture.

Trial I

From a mob of 475 mixed-aged Romney Crossbred ewes, 200 were selected on the basis of small body size and wool quality. Owing to the wide range of wool quality within the flock, however, the line selected was still variable, but largely of 46–50s count.

The sheep were divided randomly into 3 groups and were treated on 30 March 1957 as follows:

1. Control. Sixty-six ewes. No treatment.
2. Thyroxine. Subcutaneous implantations of 60 mg of *l*-thyroxine into the shoulder region of 67 ewes.
3. Neo-Hydriol. Intramuscular injections of 1 ml of Neo-Hydriol containing 40% iodine, into the thigh of 67 ewes.

The sheep were run as one mob throughout the trial, the rams being joined 12 days after treatment. Detailed lambing data were not available. All tagged ewes were shorn in random order on 23 January 1958. The principal reason for the non-appearance of a large number of ewes at shearing was loss of ear tags, as only one ewe died during the lambing period. The wool-production results are given in Table 1.

TABLE 1. WOOL GROWTH DATA—TRIAL I

	Control	Thyroxine	Neo-Hydriol
Number of sheep	47	44	53
Fleece weight, lb	9.41	9.23	9.00
Faulty fleeces, %	74.5	77.3	60.4
Style grade index	7.9	8.2	8.1
Yield % (at 16% regain)	78.9	78.9	76.4
Fibre diameter, μ	37.0	37.5	35.9
Staple length,* in.	5.9	5.8	5.8
Staple strength,* maximum load (2½ in.) lb/g	83.0	81.8	81.8

* 2 samples from the control group and 1 from the Neo-Hydriol group were not measured, owing to the badly cotted state of the fleeces.

The fleece weights do not include bellies and board locks. The measurements of staple length and staple strength (Ross and Lewis 1958) were made on four staples taken from along the mid line of each fleece. The yield and airflow fibre diameter measurements (Ross 1958a) were made on a composite sample from each group. The numerical index for the style grading of the fleeces was based on Hart (1957).

There was no significant difference between the groups in either fleece weight, staple length, staple strength, or style grading.

Trial II

Sheep

Forty full-mouth Romney ewes were selected from a line of 180 for small body frame and uniform wool type of bulk 48–50s count. These were then randomised on a weight basis into 4 equal groups on 27 February 1957.

Treatments

1. Control. No treatment.
2. Thyroxine. Two subcutaneous implants were made in the shoulder region, the first of 60 mg on 2 April 1957, the second of 90 mg on 13 November 1957.
3. Neo-Hydriol. Two intramuscular injections, each of 1 ml, were made into the thigh on 2 April and 16 October 1957.
4. Potassium iodide. An approximately isotonic solution of potassium iodine and sodium chloride was injected intramuscularly into the thigh. The first injection, given on 2 April 1957, contained 100 mg of combined iodine in an attempt to overcome quickly any iodine deficiency that might be present. Subsequent injections containing 10 mg iodine were given at fortnightly intervals throughout the trial. The last of these injections was given 10 days before slaughtering.

Body Weights

The ewes were weighed at approximately fortnightly intervals for most of the trial period but more often after the two thyroxine implants. No weights were recorded during the lambing period.

The weights were largely taken after a two-hour fast. Those that were taken after longer or shorter fasting periods have been corrected back to a two-hour basis, using data obtained from a small trial to determine the effects of different fasting times on body weight.

Heart Rates

The heart rates were usually measured on the same day as the body weights. A quietening period of at least one hour after yarding, preceded the making of the measurement. The sheep were selected at random from the mob, and were held in a relaxed position on their haunches for at least 3 to 4 minutes, before the heart beats were counted, using a stethoscope. Trials showed that after this time there was no change in heart rate for periods of up to 8–10 minutes. The heart beats per minute were calculated from the average of three counts each made over a period of 15 seconds.

Wool Data

Wool Samples. The first pre-treatment wool sample (PTS-A) was clipped on 28 February 1957 from an area on the right mid-side of each

ewe. Immediately after clipping, the skin was stretched and calipers were used to make 3 horizontal and 3 vertical measurements of each "patch" from which the area was calculated. A second pre-treatment sample (PTS-B) was clipped from the same area on 2 April, immediately before the beginning of treatment.

Twelve post-treatment samples were clipped from the same "patches" on 18 April, 1 and 22 May, 14 June, 3 July, 6 August, 6 September, 13 November, 10 December 1957, and 16 January, 18 February and 17 March 1958.

On 18 February 1958, a sample of approximately 12 months' growth was clipped from a similarly measured area on the left mid-side of each ewe.

Wool-sample Measurement. The following 6 measurements were made on PTS-A and on the full year's sample: conditioned greasy weight per 100 sq. cm, clean oven-dry weight per 100 sq. cm, yield at 16% regain, staple length, mean airflow fibre diameter, and the number of crimps per inch.

Owing to the very short length of PTS-B, only the first 4 measurements were made, and for a similar reason, only the first 3 were made on the 12 post-treatment samples.

All wool measurements affected by temperature and humidity were carried out in a conditioning room maintained at 68°F and 65% r.h. The greasy-wool samples were conditioned for at least 24 hours before weighing and a sub-sample of about half the sample weight was then re-weighed and scoured. The first two very short post-treatment samples were Soxhlet extracted with petroleum ether to remove grease, and then thoroughly washed under running water for several hours, to remove suint. All the other samples were placed in cotton bags and scoured with detergent and bicarbonate. The residual grease and suint in the scoured samples were both of the order of 0.2% on the dry weight of wool. After scouring, the wools were dried to a low regain, re-conditioned for at least 24 hours, and re-weighed. Sub-samples were oven-dried from which the clean oven-dry weight and the yield at 16% regain were calculated.

Unstretched staple length and the number of crimps per inch were measured as described by Ross and Lewis (1958) on 5 staples from each wool sample and the airflow measurements of fibre diameter were made by taking two readings on each of two 2-g samples. Staple-strength measurements were made on two staples from each full-year sample, using a breaking length of $2\frac{1}{2}$ in. (Ross and Lewis 1958).

Shearing. The sheep were shorn before treatment on 1 March 1957 and again on 19 February 1958. The fleeces were weighed, excluding bellies and board locks, and, for the second shearing only, graded for count number, style, and wool faults. The fleeces obtained on 1 March 1957 were too short to be graded.

Slaughtering and Dissection of Thyroid Glands

The sheep were slaughtered in random order at the Burnside Abattoir on 24 March 1958, the hot weights of the carcasses being

recorded. The trachea and muscle surrounding the thyroid glands were placed in numbered plastic bags, to await dissection which was completed within 4 hours from the beginning of slaughtering. It is unlikely that any serious degenerative changes occurred within this period.

Immediately after dissection the glands were weighed, part of each gland was fixed in Bouin's solution for histological study, and the remainder re-weighed and freeze dried. The total dry weight was calculated from the weight of the freeze-dried sample.

Iodine Analyses

The iodine analyses were carried out in quadruplicate on the freeze-dried portion of the glands. The method was that of the British Pharmacopoeia (1953), with minor modifications. Recoveries of added iodine were 99.2%, 98.9%, 98.7%, and 99.7%, with a mean of 99.1%, and the repeatability within quadruplicates was high, the average difference being 0.2% of the iodine estimated.

Histology

After dissecting and weighing, three transverse pieces about 5 mm thick were cut from each thyroid and fixed for 48 hours in Bouin's solution. After fixing, the pieces were transferred to 50% alcohol for 7 hours and then to 70% alcohol where they remained until required. They were then transferred successively through increasing concentrations of alcohol to xylene, and embedded in paraffin wax (m.p. 52.5°C). During preparation, no appreciable shrinkage of the thyroid pieces occurred.

A total of 81 sections (27 per piece, 5 μ thick) was cut from each thyroid, and these were stained with eosin and celestin blue. A system of random selection, restricted so that cells from the same follicle would not be measured more than once, was used to select sections, follicles, and cells for measurement of acinar cell height (Flux *et al.* 1956). The cell heights were measured using an eye piece micrometer and an oil-immersion lens, at a magnification of 650×.

A total of 96 cells was measured on each thyroid, i.e. 32 per piece, made up of 4 cells/follicle, 2 follicles/section, 4 sections/piece.

These sections were also used to obtain a measure of follicle density. A portion of each of 27 sections per thyroid was projected on to a measured area, and the number of follicles in this area was counted.

RESULTS AND DISCUSSION

Body Weight and Heart Rate

The repeatability of heart-rate measurements both within and between successive days was very high. On two days 6 months apart on which the mob was measured and then re-measured, the repeatability coefficients were 0.74 and 0.98 ($P < 0.01$). The repeatability calculated for 7 pairs of successive days ranged from 0.45 to 0.78 ($P < 0.01$).

At no time did the heart rates and body weights of the 2 iodine-treated groups differ significantly from the control group, and so the three groups have been combined in the analysis of the relationship of heart rate to body weight.

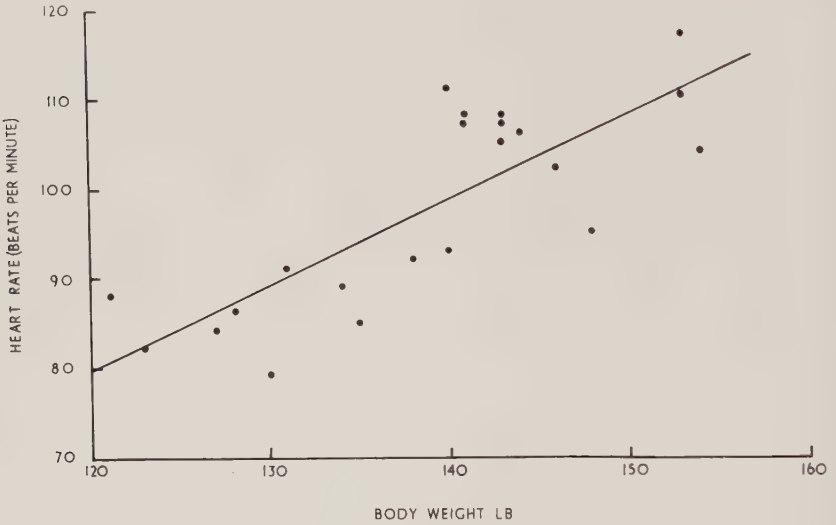

Fig. 1.—The relationship between heart rate and body weight.

It can be seen from Fig. 1 that there is a highly significant correlation ($r = 0.805$, $P < 0.01$) between mean heart rate (Y) and mean body weight (X) for the 22 days on which both were measured. Over this small range of body weights the linear regression

$$Y = 0.96\ X - 35.64$$

with a standard error of 6.8 fits the data well showing that in these 3 groups of sheep heart rate is directly related to body weight.

It would be expected that body temperature regulation and thus heart rate would be markedly affected by environmental temperature. For the same 22 days the multiple regression of mean body weight (X) and environmental temperature at the time the heart rate measurements were made (T), on the mean heart rate (Y), was

$$Y = 0.956\ X + 0.007\ T - 35.545$$

It is apparent from this regression that over the whole experiment, temperature had little effect on heart rate, and that body weight was the determining factor. However a similar regression calculated for the period before pregnancy had any marked effect on heart rate, i.e. the 11 measurement days up to July 10, was

$$Y = 0.114\ X - 0.266\ T + 86.150$$

The inverse correlation of $r = -0.623$ ($P < 0.05$) between heart rate and environmental temperature shows that over this short period heart rate was inversely affected by environmental temperature while the effect of body weight was not as important.

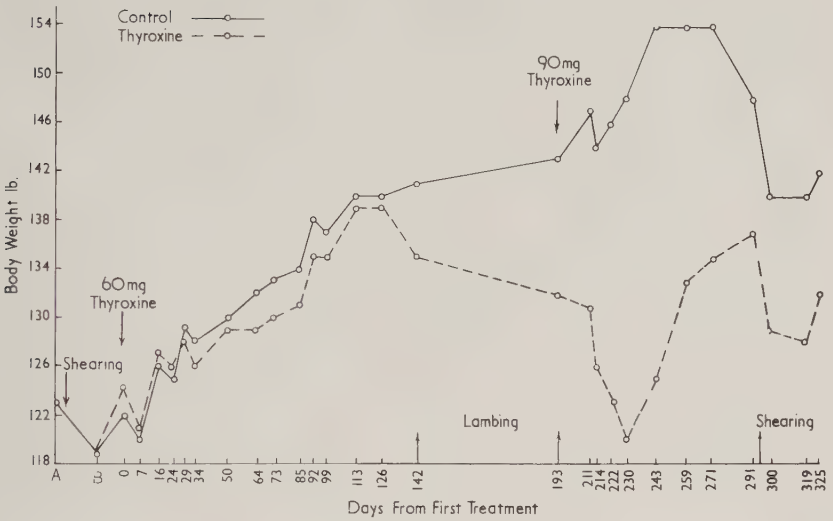

Fig. 2.—Body weight changes.

The mean body weights for the control and thyroxine groups during the trial are shown in Fig. 2.

No loss in weight significant at the 5% level was found following the April thyroxine implant. The treated sheep showed a drop of 1 lb in body weight relative to the controls after a month, and this increased to 3 lb after two months. This difference was maintained up to lambing.

The difference in body weights between the two groups at the time of the November implant although large was not significant. Following the implant, however, while the control group increased in weight the thyroxine-treated group lost a maximum of 12 lb ($P < 0.01$) 35 days after treatment, thereafter the sheep regained weight but were still 10 lb lighter than the control group at the time of slaughter.

The heart-rate changes of these 2 groups are illustrated in Fig. 3. Following the April thyroxine implant there was an elevation in heart rate which at its maximum 50 days after implantation was 9% higher than the controls. This stimulation was followed by a depression of heart rate of up to 12% ($P < 0.05$) 4 months after treatment.

Associated with the loss in body weight following the November implant there were very large increases in heart rate which reached a maximum of 66% ($P < 0.01$) 35 days after implantation. These faster heart rates were associated with an increase in loudness, increased panting and symptoms of nervousness.

At no stage in the thyroxine group did the heart rates and body weights show a significant correlation, nor were the heart rate and body weight differences between November 13 (day of implant) and December 18 (maximum heart rate and body weight response) signifi-

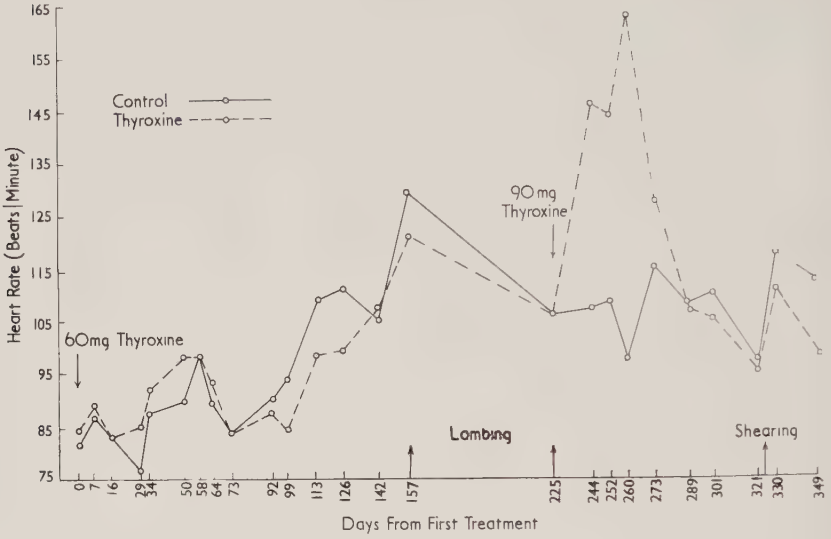

Fig. 3.—Heart rate changes.

cantly correlated. This may indicate that the sheep did not all reach their peak of metabolic rate increase at the same time.

As previously stated, at no time was there a significant difference between the two iodine-treated groups or between these groups and the controls in either heart rate or body weight. Because of this, the two iodine-treated groups have been omitted from Figs. 2 and 3 for the sake of clarity. During the trial the mean heart rate differences of the Neo-Hydriol and the potassium iodide treated groups from the controls were —1.8 and +1.8 beats/minute respectively. These differences are probably due to the corresponding differences in body weight from the controls of —2.7 lb and +3.7 lb respectively.

Fig. 3 also demonstrates an increase in heart rate during pregnancy, a spectacular drop after lambing, and a temporary stimulation following the 1958 shearing.

Although the first thyroxine implant resulted in only a very small body-weight change, relative to the control, it is difficult to attribute the effect to any cause other than thyroxine administration, especially in view of the marked body-weight loss which occurred after the second thyroxine treatment, when the sheep were grazing excellent pasture as is evidenced by the increase in weight shown by the controls.

Other workers report weight losses of up to 10 lb, associated with the wool stimulatory effects of thyroxine (Hart 1957; Coop and Clark 1958; Ross and Lewis 1958). However, again the effects obtained have been variable; Ross (1958) reported no weight loss following a 60-mg implant in 4-tooth ewes.

The primary function of the thyroid hormone is that of controlling the rate of cellular oxidation, and thus metabolic intensity. Hyper-

thyroidism is typified by large increases in basal metabolic rate, while hypothyroidism and thyroidectomy produce a very much reduced basal metabolic rate.

Body-weight changes *per se* do not give a reliable measure of metabolic rate, and thus it is desirable when dealing with metabolic hormones to have some specific measure of the associated metabolic changes.

The long fasting period (approx. 4 days) required for ruminants to reach a post-absorptive condition (Ritzman and Benedict 1938) makes it impracticable to measure basal metabolic rate in a trial of this nature. However, increases in heart, pulse, and respiration rates, and in body temperature of ruminants following thyroxine and iodinated casein administration, have been adequately demonstrated (Brody 1945; Thorbek *et al.* 1948; Blaxter 1952; Ferguson 1958).

Thus, in view of the close interrelationship of heat production, blood flow, and heart rate, it is reasonable to assume that heart-rate measurements should give an estimate of "resting" energy metabolism.

The heart-rate measurements obtained in this trial appear to be directly related to body weight rather than to a fractional power of it. A similar type of relationship between maintenance feed intake of pen-fed Merinos and body weight was found by Ferguson (1958). However, the basal energy metabolism of mature animals of different species tends to vary with approximately the 0.7 power of body weight, i.e. the metabolically effective body size (Brody 1945). Nevertheless, although heart rate may not give a direct measure of metabolic rate it does appear to be approximately proportional to it. This fact is substantiated by the response in heart rate to a metabolic stimulus such as thyroxine, and the increases which occur during pregnancy, and after shearing. These trends in heart rate are closely associated with the known trends in metabolic rate, showing the value of this measurement as an indication of metabolic rate changes.

The failure to obtain a significant increase in heart rate after the first thyroxine implant was probably due to several factors, namely, a wide individual variation, the smaller size of the implant, seasonal thyroid rhythm and the effects of environmental temperature. The mean environmental temperature on the days on which heart rate was measured from 2 April to 10 July 1957 was 51.3°F as compared with 58.1°F for a similar period after the second implant (13 November 1957 to 17 February 1958). Superimposed on this factor was the effect of quantity of fleece. The sheep were shorn on 1 March 1957, so that during the period of effectiveness of the first implant they were carrying considerably less wool, at a lower environmental temperature, than they were after the second implant when the temperature was higher. A heavy fleece affords good protection against low environmental temperatures, but Ritzman and Benedict (1938) demonstrated an inverse relationship between metabolic rate and environmental temperature after shearing. Thus at this stage the controls would be metabolising at an increased rate to maintain their body temperature which would thus reduce the effective increase in the thyroxine metabolic rate and heart rate.

In contrast to this the significantly increased heart rate associated with the November thyroxine implantation of 90 mg was of the same order as that found by Ferguson (1958) following thyroxine injection, and occurred at a time when the effects of both wool weight and environmental temperature would severely tax the not-very-efficient heat-dissipating mechanisms of the sheep. The blood circulation and consequently the heart rate would thus be greatly increased.

The reduction in heart rate which followed the increase due to thyroxine, was probably due to a temporary hypertrophy of the heart which occurs in hyperthyroid ruminants (Blaxter 1952; Brody 1945).

Reproductive Performance

A Southdown ram was joined with the boxed ewes on 16 April, that is 14 days after the April thyroxine implantation, and a second ram was joined on 21 May. Lambing commenced in September and the lambs were weaned in early January.

TABLE 2. Lambing Performance

	Ewes Mated	Ewes Lambing	Total No.* of Lambs	No. of Sets* of Twins	Lambs at† Docking
Control	10	9	15	5	11
Thyroxine	10	10	14	4	13
Neo-Hydriol	10	8	14	4	9
Potassium Iodide	10	10	16	6	12

* Alive, dead, and foetal lambs in ewes that died prior to lambing.

† One ewe in the control group had twins which died. A single lamb was mothered on, but was not counted with the lambs at docking.

The lambing data are given in Table 2. The total number of lambs conceived was very similar in all groups. One ewe in the control group and two in the Neo-Hydriol group died just prior to lambing owing to pregnancy toxaemia, all having twin lambs *in utero*. These deaths cannot be attributed to treatment effects and had no marked result on mean wool production, body weight, or heart rate of the two groups involved.

Wool Production

The restricted randomisation of the sheep on a weight basis at the commencement of the trial resulted in a range in mean group body weights of only 0.2 lb. This negligible difference between groups is reflected in the similarity of the mean wool production of the groups during the pre-treatment period (PTP-C). The values for wool weight grown in PTP-C (Table 3) have been obtained by adding the values for the 2 pre-treatment samples A and B, while for yield the average of PTS-A and PTS-B has been used. The relative values for PTS-A and PTS-B were 20.8 and 5.8 g respectively for greasy weight and 15.4 and 3.9 g for oven-dry weight.

TABLE 3. WOOL GROWTH DATA—TRIAL II[1]

	Period of Growth	Control	Thyroxine	Neo-Hydriol	Potassium Iodide
No. of sheep		9	10	8[2]	10
Greasy wt./100 sq. cm, g	PTP-C[3] X	26.6	26.4	26.4	27.2
	Tot. of samples Y	53.3	52.1	53.5	53.8
	Y/X, %	200.3	197.5	203.1	198.0
	Full year sample	35.9	36.8	36.4	34.1
Oven-dry wt./100 sq. cm, g	PTP-C X	19.4	19.2	19.2	19.4
	Tot. of samples, Y	32.4	32.4	32.7	32.9
	Y/X, %	167.3	169.2	170.5	169.4
	Full year sample	23.8	24.5	24.0	22.5
Yield, %	PTP-C X	81.6	82.4	81.7	80.9
	Mean of samples Y	72.2	73.3	72.4	72.9
	Y/X, %	88.5	89.0	88.6	90.1
	Full year sample	76.5	77.3	76.6	76.6
Staple length, cm	PTP-C	10.6	10.5	10.5	10.6
	Full year sample	14.8	15.0	15.6	15.7
Fibre diam., μ	PTS-A[4]	37.4	34.9	36.6	36.5
	Full year sample	39.0	36.7	38.0	38.6
Crimps/in.	PTS-A	3.3	3.6	3.2	3.4
	Full year sample	2.6	2.6	2.8	2.6

[1] Dead sheep omitted.

[2] One sheep was shorn at lambing owing to sickness, and therefore the full-year sample data for the Neo-Hydriol group are from 7 sheep.

[3] Pre-treatment period C.

[4] Pre-treatment sample A.

The wool-growth data for the trial are given in Table 3. It is apparent from a comparison of the total of the periodic samples or the full-year sample with wool growth during the pre-treatment period that there were no significant differences between the groups in any of the wool characteristics measured.

Greasy and oven-dry wool production/100 sq. cm was considerably higher for the total of the periodic samples than for the full year's sample. At least part of the difference was due to the increase in size of the ewes during the trial (Fig. 2). Because of the frequency of sampling, a large area averaging 332.6 sq. cm was cut at the commencement of the trial. This area was used as the basis for calculating the periodic wool growth. When re-measured on 18 February 1958, the mean area was 377.6 sq. cm which was highly correlated with the previous measurement ($r = 0.70$, $p < 0.01$). The area from which the full-year samples were cut (mean 158.5 sq. cm) would therefore have measured less in February 1957, thus resulting in a higher wool production per 100 sq. cm. In addition the frequent clipping may have stimulated wool growth.

For the periods following treatment, oven-dry wool production was calculated as mg/100 sq. cm/day for each period and the mean

level of production is shown in Fig. 4, where production for each ewe in the post-treatment periods is expressed as a percentage of its daily wool production in PTP-C. The greasy and oven-dry wool production for PTP-C averaged 142.5 and 99.2 mg/100 sq. cm/day respectively.

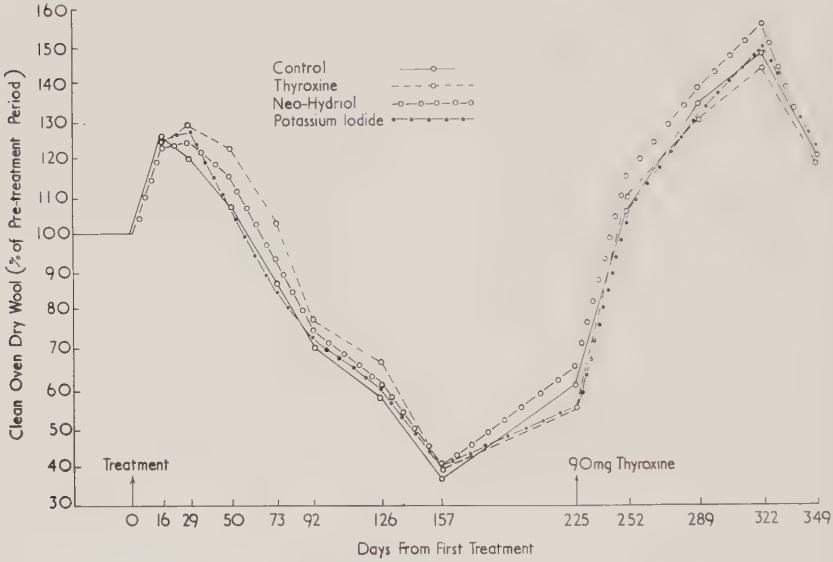

Fig. 4.—Wool production.

It is apparent from Fig. 4 that wool production followed the normal seasonal rhythm (Story *et al.* 1956) of sheep run on the Taieri Plain. The correlations of wool production between adjacent periods were very high ($r = 0.8 — 0.9$, $P < 0.01$) while the correlations between each successive period and the PTP-C fell off towards lambing but reached significant levels again after lambing. Wool production first increased between the 16th and 29th day after the April thyroxine implant. However, in neither the production in any one period nor the accumulated differences over the period from the 16th to the 126th day when total oven-dry wool production was 10.3% above controls did the increase reach the 5% level of significance.

Despite the marked increase in heart rate and the large loss of body weight following the November thyroxine implant there was no associated increase in wool growth.

The full-year fleece weights given in Table 4 do not include bellies and board locks which averaged 1.1 lb per sheep. As would be expected from the wool production figures of the periodic and full year's samples no significant differences were found between the groups. The low style grading was due to the severe "lambing break" in most of the fleeces as shown by the staple-strength tests which were made on 2 staples from each full-year sample. Although the differences between groups appear large they were not significant owing to a large within-group variation.

TABLE 4. FLEECE DATA

	Control	Thyroxine	Neo-Hydriol	Potassium Iodide
Number of sheep	9	10	7	10
Pre-treatment, lb	3.67	3.70	3.76	3.68
Full year, lb	9.23	9.24	9.54	9.55
Full year/pre-treatment, %	251	250	254	260
Style grade index	6.7	7.1	7.3	7.3
Staple strength (2½ in.)				
Work, cm lb/g	119.9	135.5	158.9	123.0
Standard error	23.1	33.0	38.4	22.7
Maximum load, lb/g	26.9	34.5	38.4	33.2
Standard error	4.6	8.9	8.3	6.4

The two trials were carried out in different districts, but the results from both trials were the same, in that neither thyroxine nor iodine administration has had any significant effect on either the quantity or quality of the fleece produced.

Other work carried out at Invermay (Ross and Lewis 1958; Ross 1958b) has shown that two-tooth Romney ewes implanted with 90 mg *l*-thyroxine showed an increase of 3.6% in their fleece weight, but this was associated with a definite upset in reproductive performance, manifested by an increased incidence of barrenness, and a lower twinning rate. The following year, 60-mg implants of *l*-thyroxine into the same ewes had no significant effect on either wool growth or reproduction. This is in contrast to other work of this nature carried out in New Zealand. Hart (1957, 1958) reported results from field trials on mixed-aged Romney and Corriedale ewes implanted with 60–90 mg thyroxine which showed a range of 2%–12% increase in clean fleece weight, improved style grading, and improved reproductive performance. Coop and Clark (1958) have shown an average increase in fleece weight of 6% in Corriedales implanted during the late summer and autumn, but were not able to demonstrate any significant improvement in either commercial grade or reproductive performance.

The metabolic effect of the second thyroxine implantation of 90 mg was considerable, as was evidenced by a marked loss of body weight and distinct stimulation of heart rate. This would indicate that the exogenous thyroxine supplied by the implant was greater than the endogenous thyroid hormone production. If this were not so the homeostatic mechanisms of suppressed thyrotrophic hormone secretion would have been expected to be able to compensate adequately by reducing the thyroxine production of the thyroid gland. In spite of this no increased wool growth could be demonstrated. This failure to obtain a significant wool growth effect with late winter and spring implantations has also been demonstrated by Hart (1955) and Coop and Clark (1958). It is interesting to note, however, that stimulation

has been obtained by thyroxine injections in August, when no response was obtained from implants (Hart 1955).

Thyroid Gland Analyses

The results of the thyroid gland analyses are summarised in Table 5.

TABLE 5. THYROID GLAND ANALYSES

	Control	Thyroxine	Neo-Hydriol	Potassium Iodide
Number of sheep	9	10	8	10
Body weight, lb	139.8	129.8	136.5	143.9
Carcass weight, lb	74.7	63.5	72.4	77.0
Thyroid gland—				
Fresh weight, g	9.93	7.61*	7.80	8.36
Fresh wt./100 lb carcass, g	13.31	11.95	10.83	10.98
Dry weight, g	2.73	2.16	2.39	2.49
Dry wt./100 lb carcass, g	3.64	3.41	3.32	3.27
Iodine in dry gland, %	0.26	0.28	0.69**	0.64**
Standard error	0.03	0.03	0.03	0.03
Total iodine in the dry gland/100 lb carcass, mg	9.75	9.41	22.74**	20.38**
Cell height, μ	6.55	5.80*	5.18**	5.19**
Standard error	0.12	0.12	0.13	0.12
No. of follicles/sq. mm	58	68	72	64

* Significant at 5% level
** Significant at 1% level
} all comparisons between control and treatment

Body Weights, Carcass Weights, and Thyroid Weights.—The correlation between body weight 24 hours before slaughtering and hot carcass weight was $r = 0.932$ ($p < 0.01$). The carcasses were inspected at the Abattoir and showed no deleterious effects due to the treatments. Because of the variability in the mean carcass weights of the groups, the thyroid weights have been calculated per 100 lb carcass weight, and on this basis showed no statistically significant difference. However, the total thyroid weights of the treated groups appear to have been reduced.

Iodine Content. Both the iodine-treated groups contained similar and significantly higher quantities of iodine than the control ($P < 0.01$). The difference between the control and thyroxine groups was small and non-significant. The standard errors indicate very low within-treatment variation.

Cell Heights. The analysis of variance of cell heights is given in Table 6.

TABLE 6. ANALYSIS OF VARIANCE OF CELL HEIGHT MEASUREMENTS

Source of Variation	d.f.	Mean Square	F	Components of Variance as % of Total
Among treatments	3	120.47	9.52**	12.15
Among thyroids within treatments	33	12.66	5.92**	10.96
Among pieces within thyroids	74	2.14	1.38*	1.84
Among sections within pieces	333	1.55	1.37**	5.24
Among follicles within sections	444	1.13	2.02**	14.22
Among cells within follicles	2664	0.56		55.59

** Significant at 1% level.
* Significant at 5% level.

The greatest source of variance was contributed by the cells within the follicles as shown by Flux *et al.* (1956) in guinea-pig thyroids. The variation among pieces, and among sections within pieces was low, indicating that the heights of the cells would not be vastly different in any part of the thyroid, and that the number of sections taken could have been considerably reduced. Other sources of variation were similar in their contribution to the total variance. The treatments, thyroxine, Neo-Hydriol, and potassium iodide, have reduced the cell heights by 11.7% ($P < 0.05$), 21.2%, and 20.7% ($P < 0.01$) respectively, from the control. There was no difference between the two iodine-treated groups.

Follicle Density. The differences in follicle density between the control and the three treatments were not significant, as shown by analysis of variance. This was mainly due to a very large within-treatment variation, the variation within thyroids being however quite low.

Soil and pasture analyses do not give a reliable indication of the iodine status of sheep because even on the same soil different pastures accumulate widely varying amounts of iodine (Johnson and Butler 1957) which is variable in its availability to grazing animals. Likewise ^{131}I studies are difficult to interpret, and indicate only the thyroidal activity of the sheep at the time of measurement. Histological and chemical examinations of the thyroid gland itself summarise all the environmental factors affecting iodine supply, and should give the best indication of thyroid activity, current iodine status, and recent history of iodine nutrition.

Excessive thyroid enlargement regarded as indicating a previous history of low iodine content was not found. The range of fresh thyroid

weights was from 4.3–14.0 g and of iodine content 0.17–0.84% on the dry basis. If the commonly accepted criterion, that a goitrous gland is one with less than 0.1% iodine on the dry weight (Marine and Lenhart 1909a) is accepted, then none of these glands was goitrous. A wide range of iodine contents of from 0.1–1.3% on the dry basis has been reported in apparently normal sheep thyroids (Dawbarn and Farr 1932; Mason 1933). Markedly hyperplastic glands with very low iodine contents weigh from 30–80 g (Marine and Lenhart 1909a and b; Hercus and Roberts 1927).

Similarly the range of thyroid acinar cell heights of 3.88–7.76 μ was close to the reported range of 4–7 μ (Butler *et al.* 1957; Munford and Kirton 1958). In goitrous lambs the cell heights are about twice the normal (Andrews *et al.* 1948).

Munford and Kirton (1958) found that very large thyroxine implants had no effect on cell heights. However, the sheep were slaughtered 28 days after treatment, which, in view of the time lag found in this work between treatment and metabolic effects, was probably too short a period.

The reduction in cell heights of the thyroxine group indicate that the thyroid was in a partial, if not a complete resting phase for at least a short time, as substantiated by the effects on body weight and heart rate. Thus there is little doubt that even though no significant increase in wool growth was obtained the thyroxine pellets were absorbed by the sheep.

None of the thyroid data have shown any difference between the two iodine-treated groups, which emphasises the similarity between the effects of the conventional prophylactic potassium iodide, and Neo-Hydriol. The fortnightly injections of potassium iodide relied on the thyroid storing sufficient of the excess iodine to tide it over until the next injection. A certain amount of the dose was presumably excreted within a very short time of administration, but the elevated thyroid iodine content of this group at slaughter, demonstrates that the potassium iodide injection was effective for at least 10 days, and that a dose equivalent to 0.7 mg iodine per day is nutritionally adequate.

It is unlikely that any toxic effects due to the administration of excess iodine as demonstrated by Wolff and Chaikoff (1948) in rats would occur with Neo-Hydriol, owing to the very nature of its mode of action in forming an iodine depot in the muscle. Thus it is apparent that Neo-Hydriol would be a valuable supplementary source of iodine for sheep.

General Discussion

The striking fact which has emerged from all the work in this field is the marked variation in the nature and degree of the responses obtained. Similar variable responses in the stimulation of milk yield of cows have been found using iodinated casein or thyroxine (Blaxter 1952).

In view of the prevalence of endemic goitre in New Zealand it is interesting to speculate on the mechanisms involved in the augmentation

of wool growth by thyroxine implantations in this country. If this effect is real then it could be due to the fact that the sheep is not getting adequate iodine for its requirements, and cannot therefore produce enough thyroxine. On the other hand it could equally well be due to the fact that the implantation has a specific effect by supplying more thyroxine than the ewe is capable of making at a particular period, in spite of an adequate iodine supply. Thus by supplying thyroxine at a time when the ewe is incapable of producing an amount of thyroxine necessary for maximum wool growth, an increase in wool production may be obtained. The higher level of wool production may not necessarily be the optimum as thyroxine may have a deleterious effect on body weight, heart rate, and reproduction, and may increase the feed consumption of the ewe beyond economic levels, as opposed to the desired effect on wool growth.

The iodine deficiency theory is an interesting one; firstly the iodine intake may be borderline and a deficiency may only become apparent under the influence of precipitating causes such as repeated pregnancies or the ingestion of goitrogens; secondly the seasonal changes in thyroid iodine content may be the reason for the critical effect of time of implant; and thirdly an apparently normal sheep may not be growing its maximum amount of wool and would respond to thyroxine, because of a latent iodine deficiency, while a sheep with a similar appearance in a euthyroid condition would exhibit no increase in wool growth. Thus Ferguson *et al.* (1956) have reported that in lambs the thyroxine requirements for normal wool growth and secondary follicle maturation are greater than the requirements for general body growth.

The normal type of relationship between fresh weight of thyroids and percent iodine on the dry-weight basis, was found for the control and two iodine-treated groups, as shown by a significant negative correlation, $r = -0.519$ ($P < 0.01$). This and the inverse relationship for the same groups between cell height and iodine content ($r = -0.81$, $P < 0.01$), point to a specific effect of iodine on gland size and histological structure, and thus to a borderline iodine intake.

This is partly substantiated by two further interesting observations. In the period in which the greatest wool response to thyroxine occurred (i.e. 30th–50th day), a negative correlation between iodine % on the dry-weight basis and wool response as a percentage of the pre-treatment period was obtained ($r = -0.432$). This correlation although not significant at the 5% level indicates that those sheep that had the lowest thyroid iodine content responded best to the thyroxine treatment. In contrast to this, a similar comparison made on the control sheep in the same wool-growth period gave a positive correlation ($r = 0.695$, $P < 0.05$), showing that the sheep with the lowest thyroid iodine content were producing the least wool. This result can only be suggestive in that the measurements of thyroid iodine were not made until 10 months after this wool-growth period.

Further, the results indicate that in the thyroxine group, the poor producers in the pre-treatment period, produced the most wool in response to thyroxine implantation (i.e. 30th–50th day), whereas the best

producers showed the smallest response. In the control group, however, those sheep that were poor producers in the pre-treatment period remained so for the period from the 30th–50th day, and similarly the best producers remained the best producers.

These facts taken together do indicate that thyroxine is possibly most effective when the sheep thyroids have a low iodine content, and thus are incapable of optimal thyroxine synthesis. Thus Labban (1957) was able to obtain a significant increase in wool growth with no increase in metabolic rate. However, Ferguson (1958) could only produce wool-growth stimulation with thyroxine doses that were large enough to be associated with marked increases in metabolic rate and feed consumption. In this trial the second thyroxine implantation produced a very large increase in metabolic rate, but no associated increase in wool growth, while the first implantation resulted in a slight wool increase, with very little metabolic effect.

The failure of thyroxine implantations to give positive responses unconditionally must have some significance. Whether, in view of the seasonal rhythm in wool growth occurring in this country, the causative mechanism is associated with a seasonal rhythm in the production of thyroxine, conditioned by a seasonal thyroid iodine content, or whether it is due to some completely unrelated factor has still to be elucidated.

However in the light of this experiment the possibility of the effect of thyroxine being due to its action in overcoming either type of goitrogen-induced thyroid inhibition or in correcting a sub-clinical iodine deficiency must not be overlooked. There is a wide range between optimum intake of an essential nutrient and the level of deficiency at which obvious symptoms appear. The recognition and correction of these borderline and more subtle deficiencies which are prone to seasonal influences and are probably fairly widespread is as important to agriculture as the correction of the more obvious acute deficiencies.

The sudden sporadic outbreaks of congenital goitre which still occur (e.g. at Wanaka, 1957) and the number of enlarged thyroid glands seen in South Island abattoirs are obvious signs pointing to the sub-optimal intakes of iodine which must exist in some areas in this country.

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References

Albritton, E. C. (Ed.) 1954: "Standard Values in Nutrition and Metabolism." pp. 70, 154. Handbook of Biological Data, American Institute of Biological Sciences. W. B. Saunders, Philadelphia.

Andrews, F. N.; Shrewsbury, C. L.; Harper, C.; Vestal, C. M.; Doyle, L. P. 1948: *J. Anim. Sci. 7:* 298.

Blaxter, K. L. 1952: *Vitam. & Horm. 10:* 217.

British Pharmacopoeia. 1953: pp. 135, 572. General Medical Council. The Pharmaceutical Press, London.

Brody, S. 1945: "Bioenergetics and Growth." pp. 177, 213, 353, 372. Reinhold Publishing Co., New York.

Butler, G. W.; Flux, D. S.; Petersen, G. B.; Wright, E. W.; Glenday, A. C.; Johnson, J. M. 1957: *N.Z. J. Sci. Tech. A38:* 793.

Butler, G. W.; Johnson, June M.; Flux, D. S.; Petersen, G. B. 1956: *Proc. N.Z. Inst. agric. Sci.* 62.

Coop, I. E.; Clark, V. R. 1958: *N.Z. J. agric. Res. 1:* 365.

Cunningham, I. J. 1951: British Commonwealth Scientific Official Conference. *Proc. Spec. Conf. Agric. 1949, Aust.* "Plant and Animal Nutrition in Relation to Soil and Climatic Factors," p. 272. H.M.S.O., London.

————1955: *N.Z. J. Agric. 91:* 602.

Dawbarn, Mary C.; Farr, F. C. 1932: *Aust. J. exp. Biol. med. Sci. 10:* 119.

Ferguson, K. A. 1958: *Proc. N.Z. Soc. Anim. Prod. 18:* 128.

Ferguson, K. A.; Schinckel, P. G.; Carter, H. B.; Clarke, W. H. 1956: *Aust. J. Biol. Sci. 9:* 575.

Flux, D. S.; Butler, G. W.; Johnson, June M.; Glenday, A. C.; Petersen, G. B. 1956: *N.Z. J. Sci. Tech. A38:* 88.

Greer, Monte A. 1955: "Modern Nutrition in Health and Disease." Ed. Wohl, M. G.; Goodhart, R. S. p. 256. Lea and Febiger, Philadelphia.

Hart, D. S. 1954: *Nature, Lond. 174:* 1018.

————1955: *Proc. N.Z. Soc. Anim. Prod. 15:* 57.

————1957: *N.Z. J. Sci. Tech. A38:* 871.

————1958: *Proc. N.Z. Soc. Anim. Prod. 18:* 153.

Henneman, H. A.; Reineke, E. P.; Griffin, S. A. 1955: *J. Anim. Sci. 14:* 419.

Hercus, C. E.; Benson, W. N.; Carter, C. L. 1925: *J. Hyg. Camb. 24:* 321.

Hercus, C. E.; Roberts, K. C. 1927: *Ibid. 26:* 49.

Hopkirk, C. S. M.; Dayus, C. V.; Simpson, B. W.; Grimmett, R. E. R. 1930: *N.Z. J. Agric. 40:* 226.

Johnson, June M.; Butler, G: W. 1957: *Physiol. Plant. 10:* 100.

Labban, F. M. 1957: *J. agric. Sci. 49:* 26.

Mason, E. 1933: *Trans. roy. Soc. N.Z. 63:* 373.

Mason, E.; Waters, D. F. 1936: *Trans. roy. Soc. N.Z. 66:* 143.

Marine, D.; Lenhart, C. H. 1909a: *Arch. intern. Med. 3:* 66.

————1909b: *Ibid. 4:* 440.

Mitchell, H. H.; McClure, F. J. 1937: *Bull. nat. Res. Coun., Wash. 99* 71.

Munford, R. E.; Kirton, A. H. 1958: *N.Z. J. agric. Res. 1:* 83.

Orr, J. B.; Leitch, I. 1929: *Spec. Rep. Ser. med. Res. Coun., Lond. 123:* 22, 66, 78.

Pearson, P. B.; Briggs, H. M.; Kammlade, W. G.; Miller, J. I.; Miller, R. F. 1949: *Bull. nat. Res. Coun., Wash.* "Recommended Nutrient Allowances for Sheep," p. 5.

Ritzman, E. G.; Benedict, F. G. 1938: *Publ. Carneg. Instn. 494:* 102, 109.

Ross, D. A. 1958a: *N.Z. J. Sci. 1:* 127.

————1958b: *N.Z. J. Agric. 97:* 377.

Ross, D. A.; Lewis, K. H. C. 1958: *Proc. N.Z. Soc. Anim. Prod. 18:* 141.

Salter, W. T. 1940: "The Endocrine Function of Iodine," p. 81. Harvard Univ. Press, Mass.
Sinclair, D. P.; Andrews, E. D. 1954: *N.Z. vet. J. 2:* 72.
Story, L. F.; Ross, D. A.; Bratt, R. L.; Lewis, K. H. C. 1956: *N.Z. J. Agric. 93:* 365.
Sykes, P. H. 1934: *Trans. roy. Soc. N.Z. 64:* 17.
Thorbek, Grete; Hansen, I. G.; Moustgaard, Johs. 1948: *J. Anim. Sci. 7:* 291.
Underwood, E. J. 1956: "Trace Elements in Human and Animal Nutrition," pp. 265, 282. Academic Press, New York.
Waters, D. F. 1938: *Trans. roy. Soc. N.Z. 67:* 463.
————1939: *Ibid. 69:* 49.
Winikoff, Dora 1957: "Preliminary Report on the Use of a Neo-Hydriol Depot as a Continuous Source of Iodine." Communicated to Australian and New Zealand Association for the Advancement of Science, January, 1957.
Wolff, J.; Chaikoff, I. L. 1948: *J. biol. Chem. 172:* 855.
Wright, E. 1958: *N.Z. J. agric. Res. 1:* 224.
Wright, E.; Sinclair, D. P. 1958: *Ibid. 1:* 477.
Young, M.; Crabtree, M. G.; Mason, E. M. 1936: *Spec. Rep. Ser. med. Res. Coun., Lond. 217:* 18.

OVULATORY ACTIVITY IN MATURE ROMNEY EWES IN OTAGO

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Summary

Ovulatory activity in 5–7 yr Romney ewes in Otago followed identical patterns in 1957 and 1958.

First seasonal ovulations had occurred in less than 10% of ewes by the end of February, in 50% of ewes by 19 March, and in all normal ewes by mid April. Cyclic ovulation continued between mid April and late August but throughout September an increasing proportion of ewes ceased to ovulate. Fifty per cent had ceased seasonal activity by 11 September. In October and November, sporadic non-cyclic ovulations occurred in 2–8% of the ewes examined.

The mean number of ovulations per ewe varied significantly depending on the stage of the season at which ewes were examined, and reached a peak value of 1.83 ovulations per ewe in April.

These observations are discussed in relation to ewe fertility.

Introduction

The number of follicles ovulating per ewe per heat sets the upper limit to fecundity in sheep (Hammond 1921). From results of Grant (1934), McKenzie and Terrill (1937), Hammond (1944), Watson (1952) and Averill (1955) it appeared that, for the breeds they studied, there were times within the breeding season when the mean number of ovulations per ewe exceeded the mean numbers found at other times.

The following investigation was undertaken, therefore, to determine (a) when seasonal ovulatory activity began in mature Otago Romney ewes and (b) whether the mean number of ovulations per ewe found at different stages of the breeding season showed any variation either within or between seasons. No systematic study of reproduction in Otago Romney ewes has hitherto been reported.

Materials and Methods

Sexually mature Romney ewes killed at the N.Z. Refrigerating Company's works at Burnside were selected for study, being both numerous and readily available throughout the year.

Sets of reproductive organs, excluding vaginas, were collected at approximately 3-weekly intervals in 1957 and fortnightly in 1958 over the period January to November. Examination of representative heads from the ewes sampled on each occasion showed them to be either full or broken-mouthed. It was assumed that the ewes were of 5–7 years of age at slaughter (Barnicoat 1957).

Collection of organs was made at the point on the chain between the pelting and evisceration operations. Organs from ewes having merino, half-bred, or hogget-type wools were rejected.

The ovaries were examined to establish the number of corpora lutea, corpora albicantia, and corpora atretica present for each ewe. Some ovaries were sliced longitudinally or sectioned (at 10 μ in paraffin blocks or 20 μ as frozen preparations) where the interpretation of superficial or macroscopic details was in doubt. Paraffin sections were stained with Lilly's haematoxylin and eosin, and frozen sections with Lilly's haematoxylin and Sudan Red O. Interpretation of the findings were based on the findings of Warbritton (1934), Grant (1934) and Quinlan and Mare (1932).

Reproductive organs exhibiting gross morphological abnormalities were examined in detail and their deformities or anomalies recorded.

Statistical Methods. To establish the median dates of accession to first seasonal ovulation and recession of activity, a modified form of the probit method of Litchfield and Fertig (1941) for graphic solution of dosage-effect curves was used.

Standard errors by this method were obtained from

$$\text{S.E. (ET 50)} = S/\sqrt{\frac{N}{2}}$$

Where ET 50 = estimated date for occurrence of seasonal ovulation in 50% of ewes

S = half the time period elapsing between first occurrence of ovulation in 16% and in 84% of ewes

and N = the number of ewes examined during this period.

Because of the doubtful validity of standard errors of mean numbers of ovulations, the proportion:

$$\frac{\text{Number of ewes with multiple ovulations}}{\text{Number of ewes with single ovulations}}$$

was also tested by χ^2 tests in confirmation of data derived from mean numbers of ovulations per ewe.

Results

General

Sets of reproductive organs from 3932 aged Otago Romney ewes were examined during 1957 and 1958. Of these, 19 sets were discarded because of morphological or functional abnormality. Fifteen sets of organs exhibited morphological abnormalities ranging from ovarian agenesis and bilateral aplasia of uterine horns and tubes to unilateral aplasia or hypoplasia of uterine horns and infantility (total organ weight < 25 g). In four ewes the ovaries contained simultaneously one or more recently formed corpora lutea (i.e. within 3 days of slaughter) and mature active corpora lutea (6–14 days old). These four ewes were discarded because of this functionally unusual superovulation.

Of the remaining 3913 ewes, 43 had large unovulated and partially luteinised follicles of 15–20 mm diameter either with or without normal corpora lutea in their ovaries. A further 19 ewes had small corpora

lutea atretica (< 3 mm diameter) in their ovaries as well as normal corpora lutea. Neither of these two forms of luteal tissue were classified as ovulations.

Two thousand seven hundred of the ewes examined had normal corpora lutea varying in age from a few hours to 17 days in their ovaries at slaughter. There were 1201 ewes with 1 corpus luteum, 892 ewes with 2 corpora, 102 with 3 corpora, 4 with 4, and 1 with 5 corpora lutea at slaughter.

1213 ewes examined had no corpora lutea in their ovaries. These ewes were distributed mainly in the January to March samples and in the samples collected after September. The latter group often had recognisable corpora albicantia present and all showed some degree of follicle development.

Seasonal Trends in Ovulatory Activity

Table 1 shows the percentages of ewes examined in each month which had ovulated just prior to slaughter, and Fig. 1 shows the percentages ovulating in each sample collected, plotted against the relative dates of collection.

First seasonal ovulations had occurred in none of the 86 ewes examined in January 1957 and in only 4% of 190 ewes examined in February 1957 and 8.9% of 336 ewes examined in February 1958.

By probit analysis it was calculated that first seasonal ovulation would have occurred in 50% of ewes by 21 March ± 2.3 days in 1957 and by 17 March ± 1.4 days in 1958. The difference between these dates was not significant.

Between mid April and late July in both years over 99% of ewes examined had active corpora lutea in their ovaries. Three out of 88 ewes collected on 16 April 1957 had failed to ovulate, 2 having large partially luteinised follicles in their ovaries. One ewe of a sample of 170 collected 28 April 1958 had failed to ovulate prior to that date. In 1 ewe of 114 collected late in June 1957 and 1 ewe of 117 collected mid July of the same year no luteal tissue was present in the ovaries at slaughter.

During August and September in both years, increasing proportions of ewes were found in successive samples with only corpora albicantia in their ovaries while in the October and November samples none of the few ewes with active corpora lutea had regressing corpora simultaneously present in their ovaries. It was calculated that 50% of ewes had ceased cyclic seasonal ovulation by 6 September ± 3.3 days in 1957 and by 16 September ± 1.8 days in 1958. The difference between these dates was not significant.

The Number of Ovulations per Ewe

Table 1 shows the monthly variation in both absolute and mean numbers of ovulations per ewe found in 2700 ewes which had ovulated prior to slaughter in 1957 and 1958. In Fig. 2 the mean number of ovulations per ewe examined has been plotted against the respective

TABLE 1. RELATIONSHIP BETWEEN TIME OF SEASON AND OVULATORY ACTIVITY IN AGED ROMNEY EWES

Month	Year	Ewes Examined No.	Ewes Ovulating No.	Ewes Ovulating %	Ovulations per Ewe Mean ± S.E.	No. of ewes with C.L. 0	1	2	3	4	5
Jan.	1957	86	—	—	—	86	—	—	—	—	—
	1958		—	—	—	—	—	—	—	—	—
Feb.	1957	190	8	4.2	1.25 ± 0.015	182	6	2	—	—	—
	1958	336	30	8.9	1.30 ± 0.064	306	21	9	—	—	—
Mar.	1957	63	39	61.9	1.54 ± 0.078	24	18	21	—	—	—
	1958	424	276	65.1	1.57 ± 0.034	148	130	135	11	—	—
Apr.	1957	424	417	98.4	1.86 ± 0.028	7	102	275	37	3	—
	1958	360	357	99.1	1.82 ± 0.031	3	92	234	29	1	1
May	1957	132	132	100.0	1.67 ± 0.044	—	47	82	3	—	—
	1958	354	354	100.0	1.76 ± 0.025	—	97	249	8	—	—
June	1957	138	137	99.9	1.60 ± 0.045	1	58	76	3	—	—
	1958	314	314	100.0	1.52 ± 0.029	—	158	150	6	—	—
July	1957	117	116	99.9	1.42 ± 0.046	1	67	49	—	—	—
	1958	60	60	100.0	1.38 ± 0.068	—	38	21	1	—	—
Aug.	1957	162	124	76.5	1.28 ± 0.069	38	93	27	4	—	—
	1958	239	212	88.7	1.18 ± 0.015	27	173	39	—	—	—
Sept.	1957	47	18	38.3	1.17 ± 0.086	29	15	3	—	—	—
	1958	149	89	64.7	1.15 ± 0.056	60	76	13	—	—	—
Oct.	1957	86	7	8.1	1.43 —	79	4	3	—	—	—
	1958	70	5	7.1	1.00 —	65	5	—	—	—	—
Nov.	1957	95	2	2.1	—	93	1	1	—	—	—
	1958	66	3	4.5	—	63	—	3	—	—	—

dates of collection for each sample and in Fig. 3 the mean number of ovulations per ewe ovulating has been similarly plotted for each sample.

Chi-square analysis of the proportion:

$$\frac{\text{No. ewes with multiple ovulations}}{\text{No. ewes with single ovulations}}$$

failed to show significant differences between the same monthly values in consecutive years. This proportion, however, rose significantly from February and March to a maximum in April, and thereafter declined with successive months until September.

Fig. 1. RELATIONSHIP BETWEEN TIME OF YEAR AND PERCENTAGE OF MATURE ROMNEY EWES OVULATING

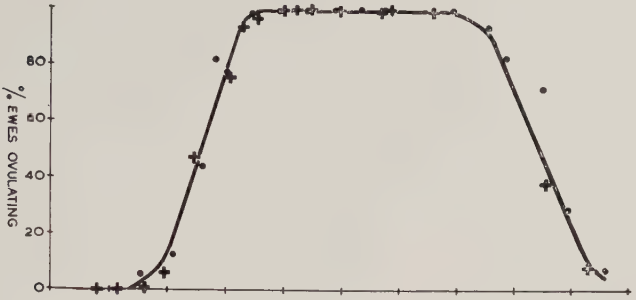


Fig. 2. RELATIONSHIP BETWEEN TIME OF YEAR AND MEAN NUMBER OF OVULATIONS PER EWE EXAMINED.

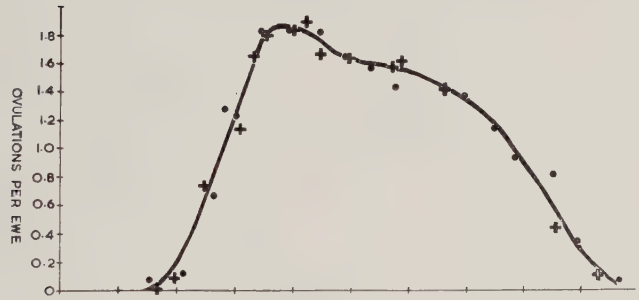
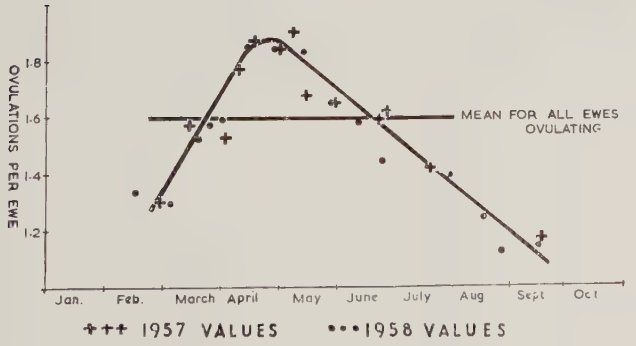


Fig 3. RELATIONSHIP BETWEEN TIME OF YEAR AND MEAN NUMBER OF OVULATIONS PER EWE OVULATING.



Between-month comparisons of the mean number of ovulations per ewe ovulating were made for the 1957 and 1958 data, both separately and pooled. On the pooled data, the mean monthly value for April (1.85) was significantly higher than those for March (1.56) and for May (1.73) and the succeeding months.

On the 1957 data alone, monthly mean values for May and June were not significantly different while those for April and May were so.

On the 1958 data alone, monthly means for April and May were not significantly different whereas those for May and June were different. On the pooled data, March and June means were the only ones for which the number of ovulations per ewe ovulating were not significantly different. All other comparisons of monthly means showed significant differences between months.

Thus during April in both 1957 and 1958, a significantly greater proportion of ewes had multiple ovulations as opposed to single ovulations, giving rise to a significantly higher mean number of ovulations per ewe for ewes ovulating in that month compared with other months.

Discussion

Seasonal Incidence of Ovulation

While a small proportion of mature Romney ewes (< 10%) experienced their first seasonal ovulation before March, the majority (over 80%) commenced ovulatory activity during the month of March and in both seasons studied. The median dates for first seasonal ovulations in 1957 and 1958 were not significantly different. Climatic conditions and consequently grass growth rate did vary between the two years (e.g. grass minimum temperatures continued rising throughout February 1957 whereas they were falling in February 1958), and it appeared that the seasonal onset of ovulation was unaffected temporally by these factors although monthly maximum temperatures and daylight hours showed similar declines in the two years. Grant (1934) suggested that abundant feed might permit expression of full oestrus at pre-seasonal "silent heats" but this study provided no evidence on this subject.

The pattern and rate of accession to seasonal ovulation in these Romney ewes closely resembled the patterns and rates of occurrence of first oestrus in mature Romneys mated in Manawatu (Goot 1949) and near Ashburton (Haughey pers. comm.). The median date of first oestrus for 1812 mature Romneys near Ashburton in 1957 was 30 March (Haughey pers. comm.) while the median date for first ovulation was 19 March in the Otago ewes studied. The difference between these dates is more likely due to the observation of "silent heat" ovulations in the Otago ewes, these not being apparent in Haughey's study, than to the 2° difference in latitude between Ashburton and Otago.

Unlike the more widely studied Merino (Quinlan and Mare 1932; Kelley and Shaw 1943; and many others) the mature Romney exhibited a very rapid transformation from anoestrum to the actively ovulating state. As 80% of ewes had their first seasonal ovulation in rather less than 30 days it would appear that selection within the breed for early breeding would be relatively ineffective. McKenzie and Terrill (1937) and Goot (1949) reached a similar conclusion from studies based on times of first matings in consecutive seasons for ewes of British breeds. Schinckel (1954 a and b) found that ovulations could be induced in Merino ewes by introducing rams into the flock in spring and early summer months. As the British breeds have longer and more intense anoestrous periods than the Merino it is considered that their seasonal

onset of ovulation would be less influenced than that of Merinos by the unaccustomed presence of the ram. Periodic examination of Corriedale-Halfbred ewes during this study suggested that their onset of seasonal activity occurred about 2–3 weeks earlier than that in Romneys (Averill, unpublished data).

Cyclic ovulatory activity was apparently continuous in mature Romney ewes between mid April and mid August (although persistent corpora lutea may have been present in some ewes studied). From mid August increasing proportions of ewes examined had ceased cyclic ovulation. Walker (1943) found that only 2 out of 7 Romney 2-tooth ewes exhibited oestrus after mid August. By October the only ovulations which were occurring were sporadic and non-cyclic. Hammond (1944) and Robinson (1950) observed sporadic ovulations in a small proportion of Suffolk-cross sheep at times well outside their normal breeding season and Hafez (1952) and Averill (1955) found that "silent heat" ovulations were common after cyclic seasonal activity had ceased.

Thus for mature Romneys cyclic ovulatory activity was restricted in 2 consecutive seasons to the 4-months period between mid April and mid August in the Otago area. The extent of this period and its time of occurrence in localities of different latitudes relative to that in Otago is unknown although further work is aimed at determining this.

The Number of Ovulations per Ewe

Both the mean number of ovulations per ewe and the proportion of ewes with multiple versus single ovulations showed significant fluctuations within the periods of cyclic ovulatory activity in both seasons of this study. The pattern of initial rise, peak, and steady decline in the mean number of ovulations per ewe ovulating (Fig. 3) closely parallels data previously obtained in British breeds by McKenzie and Terrill (1937), Hammond (1944), and Averill (1955) and in Merinos by Watson (1952). This within-season fluctuation doubtless accounts also for the observation (Grant 1934) that Scottish ewes ovulating before 1 January shed more eggs per ewe than those ovulating after that date, and the often-recorded fact that the highest proportion of multiple births in sheep occur early in the lambing season (Heape 1899; Marshall 1904, 1908; and many others). McKenzie and Terrill (1937) found that the mean number of ovulations per ewe at pre-seasonal "silent heats" was lower than the means for first seasonal heats, and parallel studies of oestrous behaviour and ovulatory activity should reveal whether the mean number of ovulations per ewe reaches its peak at the second, third, or later seasonal heats. From laparotomies on 20 mature Romney ewes mated in April 1957, Averill and Mitchell (unpublished data) recorded an average of 2 ovulations per ewe, a figure in close agreement with the mean of 1.86 corpora lutea found in 424 Romney ewes collected in the same month in this study.

No correlation could be found between fortnightly grass growth rate figures (kindly made available from Invermay Research Station) and the fluctuations in the mean numbers of ovulations per ewe. In both years the initial rise and the peak ovulatory period coincided with and followed periods of rapidly declining grass growth rate. Watson (1952)

reported that prolific spring grass growth was accompanied by a low incidence of twin ovulations in Australian Merino ewes while Averill (1955) observed a significant within-season fluctuation in the mean number of ovulations per ewe in Suffolk ewes fed a fixed daily ration of dry feed.

It is suggested, therefore, that in the seasonally polyoestrous ewe progressive physiological changes, probably endocrine in nature, result in a marked tendency towards an initial increase and eventual decline in the number of follicles ovulating at successive oestrous periods. Such a phenomenon is necessary to account for the fluctuating proportion of ewes having multiple versus single ovulations during the period in which all normal ewes are ovulating cyclically. There is evidence (Brambell and Rowlands 1936; Watson 1957) that ovulatory activity fluctuates within the breeding seasons of species other than sheep.

Data for mean numbers of ovulations per ewe have been presented for several breeds of sheep and these are considered to be affected by both breed and age. The value of 1.61 ovulations per ewe for the mature Romney ewes studied here is greater than those of 1.17 and 1.33 found by Wallace (1954) in 2 groups of 20 Romney ewes, but the same as the 1.60 ovulations per ewe found in a further group of 20 flushed ewes. Similarly, Marshall (1904) reported 1.25 ovulations per ewe from 55 Scottish ewes while Grant (1934) found 1.87 ovulations per ewe in 441 similar sheep and Hammond (1921) found 1.45 ovulations per ewe in 80 pregnant Suffolk ewes while Averill (1955) found an average of 2 eggs shed per ewe in 130 Suffolk ewes. Clearly, both the sample size and the time of sampling within the breeding season can markedly alter the mean values derived for the number of ovulations per ewe, and in view of the significant within-season fluctuations single figures for mean numbers of ovulations per ewe are of limited value in assessing the fecundity of different breeds.

To obtain maximum fecundity in sheep it would appear necessary to ascertain the times of occurrence of the peak ovulatory activity for ewes of different breeds and age groups in their separate environments. For mature Romney ewes in Otago this period fell between mid April and mid May in both 1957 and 1958.

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References

Averill, R. L. W. 1955: *Stud. Fertility 7:* 139.
Barnicoat, C. R. 1957: *N.Z. J. Sci. Tech. A38:* 583.
Brambell, F. W. R.; Rowlands, I. W. 1936: *Phil. Trans. B226:* 71.
Goot, H. 1949: *N.Z. J. Sci. Tech. A30:* 330.
Grant, R. 1934: *Trans. roy. Soc. Edinb. 58:* 1.
Hafez, E. S. E. 1952: *J. agric. Sci. 42:* 189.
Hammond, J. 1921: *Ibid. 11:* 337.

Hammond, J. (Jnr.) 1944: *Ibid. 34:* 97.
Heape, W. 1899: *J. R. agric. Soc. 10:* 217.
Kelly, R. B.; Shaw, H. E. B. 1943: *Bull. Coun. sci. industr. Res. Aust. 166.*
Litchfield, J. T.; Fertig, J. W. 1941: *Bull. Johns Hopkins Hosp. 49:* 276.
Marshall, F. H. A. 1904: *Trans. Highl. agric. Soc. Scot. 16:* 34.
————1908: *Ibid. 20:* 139.
McKenzie, F. F.; Terrill, C. E. 1937: *Mo. agric. Exp. Sta. Res. Bull. 328.*
Quinlan, J.; Mare, G. S. 1932: *17th Rep. Div. vet. Sci. Anim. Ind., S. Afr.*, p. 663.
Robinson, T. J. 1950: *J. agric. Sci. 40:* 275.
Schinckel, P. G. 1954a: *Aust. J. agric. Res. 5:* 465.
————1954b: *Aust. vet. J. 30:* 189.
Walker, D. E. 1943: Thesis, Lincoln College.
Wallace, L. R. 1954: *J. agric. Sci. 44:* 60.
Warbritton, V. 1934: *J. Morphol. 56:* 181.
Watson, J. S. 1957: *N.Z. J. Sci. Tech. B38:* 451.
Watson, R. H. 1952: *Aust. vet. J. 28:* 1.

WEATHER CONDITIONS ASSOCIATED WITH OUTBREAKS OF FACIAL ECZEMA

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Summary

To obtain more definite information than that available to date on the weather conditions associated with outbreaks of facial eczema, the records from climatological stations in districts in which outbreaks of facial eczema frequently occur were examined.

The data indicate that a season can be considered potentially dangerous *either* if the soil temperature at 8 inches, measured at 9 a.m., has reached an average of 62.5°F or over during November, *or* if the main body of moisture in the soil, as distinct from surface layers wetted by smaller rains, has reached a deficit of 1½ in. by the end of November.

A more definite judgment can be made by the end of December. It appears there is a high probability of subsequent outbreaks if the 8 in. soil temperatures average over 65°F during December, and there is no "soaking" rain during December. By soaking rain is meant quantities of precipitation greater than that required to bring the soil up to field capacity. The data do not suggest that such rains automatically render a season safe, but that if soil temperatures are marginal, such rains, particularly if spread over several days, will reduce the probability of widespread outbreaks.

The commencement of the first toxic period in a season, as judged by liver damage in lambs grazing in the field, appeared to be *preceded* either by two or more periods when falls of rain greater than just a few points are accompanied by or immediately followed by two or more successive nights with grass-minimum temperatures of 54°F or over, or alternatively by a single prolonged group of high grass-minimum temperatures with rain. Also, the rain that was judged to initiate the first toxic period was itself *accompanied* by or immediately followed by two or more successive nights when grass-minimum temperatures were 54°F or higher. It appeared that where a period of high grass-minimum temperatures was accompanied by particularly heavy or continued rain, its effectiveness in either inducing toxicity or preparing pasture for toxicity was reduced.

Periods of high grass-minimum temperatures with rain arise from weather disturbances accompanied by inflows of warm moist air. Meteorological conditions which result in this situation are described. They can generally be foreseen a day or two ahead.

Introduction

Although the occurrence of facial eczema at any particular site may be dependent on a complex interaction of factors such as topographical aspect, soil fertility, pasture composition, and stock management (Levy and Smallfield 1942), weather conditions in a district are often of overriding importance in determining whether widespread

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outbreaks occur (Levy and Smallfield 1942; Filmer 1956). Consequently it is important to know whether there are some features of weather conditions which allow a prior assessment of either the degree of danger developing in a district or the time when liver damage can be expected to commence.

Following the 1937-38 outbreak of facial eczema, Cooper and Walker (1940) carried out an examination of the weather conditions during spring, summer, and autumn at a number of climatological stations in the North Island for the seasons 1915-16 to 1938-39.

Their main conclusions and suggestions were as follows:

(1) There was a correlation between serious outbreaks of facial eczema and seasons in which minimum temperatures were warmer than normal as judged by integrated deviations of mean monthly air temperatures for the whole period November to April. There was a similar association between soil temperatures and serious outbreaks of facial eczema.

Note.—As the outbreaks of facial eczema generally occur during February, March, or April, those observations which refer to temperature conditions during the whole period November to April do not in themselves provide a basis for predicting early in the season whether outbreaks are liable to occur later in that season.

(2) From an examination of their data to see whether air temperature deviations up to the end of December or January could serve as a basis for prediction, it was concluded that "there is no certainty that at the end of December a positive deviation will remain positive . . . , nor is there any certainty that a negative deviation at the end of January will not be followed by positive deviations in succeeding months."

(3) It was suggested that "a definite statement could be given at the end of each month or fortnight as to whether temperature conditions were dangerous or not . . ."

Note.—There were no data presented to indicate the extent or duration of warmer-than-normal temperatures required to render conditions dangerous.

(4) It was concluded that "the soil moisture condition" as judged by the Meyer ratio of rainfall to saturation deficit "is not a factor of primary importance."

Largely as a result of these suggestions, the Department of Agriculture requested the N.Z. Meteorological Service to supply, twice monthly from the beginning of November to the end of April, a summary of air and soil temperatures from eleven widely distributed weather recording stations (Filmer 1956). They did not ask for rainfall data. Last season arrangements were made to supply the temperature data weekly. The information is now "transmitted immediately to all officers of the Department in districts prone to facial eczema and enables them to broadcast warnings when temperatures are above normal" (Filmer 1957).

Experience in the period of nearly two decades since that original work by Cooper and Walker has indicated:

(a) That soil moisture conditions are almost certainly a factor of importance (Levy and Smallfield 1942; Filmer 1957).

(b) That although the relationship between major outbreaks of facial eczema and seasons which were, as a whole, warmer than normal has generally held, an outbreak which, although not extremely serious, was described as "widespread" (assessment of J. F. Filmer) occurred in the Waikato in a season, 1948-49, in which integrated deviations of air temperature were well below normal and soil temperatures were also below normal (Simmons 1951).

(c) It is still uncertain whether deviations of air temperature are adequate for predicting in various districts whether outbreaks of facial eczema are liable to occur subsequently during that season.

As Cooper and Walker had concluded that deviations of air temperature up to the end of December and January did not appear a useful basis for predicting dangerous conditions, it remains to be seen whether the data available indicate that shorter-term positive deviations of temperature give a prior indication of danger. As it is apparent both from Simmons' data and the information presented in this paper that there are few seasons in which there is not some period of a fortnight to a month when temperatures are above normal, an isolated occurrence of such conditions would be of little predictive value. On the other hand, the occurrence in a district of a period of a fortnight or a week of above-normal temperatures in the period immediately preceding rain might possibly indicate whether conditions can be considered dangerous or not. An assessment of whether the half-monthly or weekly deviations of temperatures mentioned above did give such information was obtained by comparing the information from the official recording station in the Gisborne area, with the dates of commencement of the toxic periods at Manutuke facial eczema experimental farm which is in the Gisborne district (Table 1). Liver damage occurred in nine seasons. The deviation of mean air temperature in the preceding half month was, however, positive in only five seasons and it was negative or nil in the remaining four seasons. There was a similar lack of concordance with the temperature deviation during the preceding week.

The above observations and the frequencies with which warnings based primarily on temperature deviations have been issued when outbreaks did not occur (McMeekan 1956) suggest that the situation is governed by some definite set of weather circumstances rather than just a deviation of mean air or soil temperatures from the normals for a particular district.

However, it was doubtful if any single climatological measurement would be an adequate index of such weather circumstances, and a detailed empirical examination of the complex body of data arising from many years of observations at various climatological stations was an almost impossible task. Hence the first problem was to select a hypothesis concerning the origin of toxicity in pastures as a guide to the examination of the weather records.

TABLE 1. DATES OF COMMENCEMENT OF TOXIC PERIOD AT MANUTUKE EXPERIMENTAL FARM AND THE DEVIATION FROM NORMAL OF THE MEAN AIR TEMPERATURE AT GISBORNE CLIMATOLOGICAL STATION

Season	Start of Toxic Period	Deviation of Mean Air Temperature for Previous Half Month
1944-45	1 Mar.	—0.1°F
1945-46	Nil	
1946-47	9 Feb.	0.0
1947-48	Nil	
1948-49	4 Mar.	+1.7
1949-50	24 Mar.	−1.3
1950-51	28 Feb.	−1.5*
1951-52	Nil	
1952-53	Nil	
1953-54	2 Mar.	+2.1
1954-55	26 Feb.	+0.4
1955-56	27 Jan.	+1.2
1956-57	3 Feb.	+1.9
1957-58	Nil	

* This period 1-15 February
For period 16-28 February deviation—1.1.

It had been suggested many years ago that fungi or other micro-organisms in the soil, or the pasture, might be implicated in the induction of toxicity. Evidence to direct serious attention to this possibility came from work at Grasslands Division in 1956. It was found that when ryegrass was grown in controlled climate cabinets under temperature, light, and humidity conditions similar to those that had occurred immediately preceding and during serious outbreaks of facial eczema, the ryegrass gave the flush of growth expected but it was not toxic. The implications of this situation, and also of farmer reports of instances where topdressing with copper sulphate had prevented outbreaks were tested in a small-scale field trial carried out in conjunction with the Economic Service of the Meat and Wool Board. It was found that liver damage was prevented where copper sulphate was sprayed on pastures at rates and times of application chosen to give it high effectiveness as a fungicide (Mitchell 1957) A fungus concerned has been located and identified by Thornton and Percival (1959).

It was considered probable that a final period of a high level of microbiological activity, resulting in a sudden occurrence of extreme toxicity, was preceded by a population build up during the preceding weeks or months. Hence it was judged that most information would come from an assessment of the temperature and moisture conditions of pasture and of the surface layers of the soil during the preceding spring as well as the summer and autumn.

METHODS

As most of the measurements taken at climatological stations do not give direct information on these conditions, it was necessary to seek

those which could be used as indices of the situation, and which gave most consistent accordance with the presence or absence of outbreaks.

After an examination of the information available concerning air temperature, rainfall, evaporation, wind flow, hours of sunshine, and cloud cover, it was concluded that the most useful information was given by (1) the temperature of the soil at 8 in., (2) a calculation of soil moisture status from the balance between rainfall and evaporation, and (3) grass-minimum temperatures.

For a number of the official climatological stations, measurements of soil temperature are available for depths of 4 in., 8 in., 1 ft, and 3 ft. These measurements are made at 9 a.m. each day. Diurnal variations in temperature can be considerable at a depth of 4 in., are small at 8 in., and negligible at 3 ft, but there is a lag of a week or more before measurements at 3 ft reflect temperature trends near the surface. Also, because of the relatively slow diffusion of heat through the soil, the 9 a.m. reading at 4 in. indicates the minimum rather than the mean of the temperature over a 24-hour period. Accordingly it was considered that for a 9 a.m. measurement the temperature at 8 in. would give the best indication of the general trend in warming or cooling of the upper layers of the soil.

For soil moisture it was judged that there was a requirement not so much for a statement of the overall deficit or surplus resulting from the pattern of rainfall during a season, but for knowledge of the distribution of wet and dry zones within the soil. Ideally the latter should be determined from the day to day balance between the amount of rain which falls and the evapo-transpiration during the day. In the exploratory work this was done. However, the accuracy given by such a procedure can be more apparent than real, for the rate of loss of moisture from an area of pasture land is governed by a complex interaction of climatological, vegetation, and soil factors (Mitchell and Closs 1958). It was therefore considered that a considerably simpler procedure for estimating the pattern of distribution of moisture in the soil during the course of a season was more appropriate at the present stage of knowledge. Accordingly the estimate of the moisture status of the soil was derived from the balance between the rainfall during each third of the month and the evaporation from an open water surface in the corresponding period. Daily falls of rain of 5 points or less were ignored and the ten-year average figure used for the estimate of evaporation. More detailed procedures were used in exploratory work, but it was found that such a generalised approach brought out the main features of the seasonal soil moisture pattern and at the same time avoided the complex and time consuming calculations required for arriving at an "accurate" daily balance of rainfall and estimated evapotranspiration.

Two basic generalisations were utilised to enable this information to be used to show in diagrammatic form the pattern of distribution of moisture in the soil during the course of a season. The first of these was that the soil under a pasture both dries and wets from the surface downwards. The second was that there is relatively little capillary movement of moisture, so that both wetting and drying move down-

wards in the soil on a definite face with a relatively sharp boundary between soil at field capacity and soil at wilting point. To avoid complication arising from differences in moisture holding capacity of various soil types, deficits from field capacity are shown as inches of water.

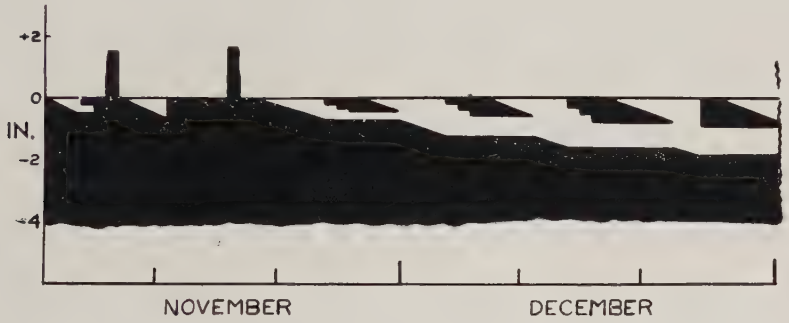


Fig. 1.—Estimated soil-moisture status during November and December 1948 at Ruakura.

To illustrate the manner in which the diagrams of soil moisture distribution were prepared, the procedure used is outlined in detail for November and December 1948 (Fig. 1 and Table 2). From the data

TABLE 2. RAINFALL AND EVAPORATION DURING NOVEMBER AND DECEMBER 1948—RUAKURA

	Total Rainfall* (100 points = 1 in.)	No. of Raindays*	Av. Evap. per Day
Nov. 1–10	186	3	12
Nov. 11–20	227	7	13
Nov. 21–30	42	3	13
Dec. 1–10	57	3	14
Dec. 11–20	71	3	14
Dec. 21–31	90	1	15

* For days when over 0.05 in.

for September and October it was calculated that the whole of the soil profile was at field capacity at the beginning of November. Accordingly the whole profile is shown as black, i.e. wet soil. With an average daily evaporation rate of 0.12 in., a moisture deficit of 0.48 in. was considered to have arisen by 4 November and is shown as a small white, i.e. dry, zone at the top of the profile. During the period 1-10 November, there were three days with rain of over 0.05 in. and the total fall on these three days was 1.86 in. These falls are grouped and plotted as an increment in moisture during three consecutive days commencing at the centre of the period, i.e. on 4th, 5th and 6th. The rainfall is sufficient to wipe out this deficit, bringing all the soil back to field capacity, and to leave a surplus for drainage through the soil, or surface runoff, of 1.50 in. This surplus is shown as a vertical black column reaching above the zero line (field capacity). It is assumed that none of the

surplus remains lying on the surface as free water. After the rain period, drying is assumed to recommence to give by 10 November, an estimated deficit of 0.48 in. at the top of the soil, with all the underlying soil at field capacity.

In the next 10-day period, there are 7 days with rain and a surplus in the period of 1.66 in. of moisture. A deficit at the 20th of 0.26 in. has increased to 0.65 in. by 24th, but the falls of rain over 5 points during this period totalled only 0.42 in., i.e. the deficit is greater than the fall. Consequently there is a newly wetted layer of soil on top with a small dry layer below it, then the main zone of original wet soil below that. After the rain the entire loss of moisture is assumed to occur first from the recently wetted surface layer and it is not until that has been exhausted that moisture loss is resumed from the zone of moist soil below it. Similarly, the quantities of rain in each of the three periods in December are less than the existing deficit. Hence they are also shown as falls which wet the surface but leave a zone of dry soil below them.

The rates of evaporation in a district will be higher in a warm season than indicated by the averages given here and lower in a cool season, i.e. the amount of moisture in the soil will be somewhat over-estimated in a warm season and under-estimated in a cool season.

The choice of a suitable index of the temperature of the air around the grass presented some difficulty. Three measurements were available, namely daily air maximum and daily air minimum, both of which are taken at 4 ft above the pasture in a Stevenson screen, and grass-minimum, i.e. the minimum temperature at one inch above the soil surface in a short pasture. Weather conditions govern whether there are large or small differences between the three measurements. Such differences are greatest on sunny days with clear calm nights and least during windy overcast weather. The decision to use grass-minimum temperature as the index was guided by three considerations. Firstly, it is a direct measurement of temperature around the grass during the night. Secondly, the occurrence of two or more successive nights when grass-minimum temperatures are high is normally an indication of a period of warm humid conditions considered associated with the induction of toxicity in the pasture. Thirdly, where periods of a week or more are considered, the 9 a.m. measurement of the temperature of the soil at 8 in. is a reasonably good, integrated index of general temperature levels within a pasture.

For the examination of relationships between preceding weather conditions and subsequent presence or absence of widespread outbreaks in a district, the climatological station at Ruakura was chosen as representative of Waikato, and recording stations in the Ohakea-Bulls-Palmerston North area as representing the Manawatu-Rangitikei district. For Ruakura and the Manawatu-Rangitikei stations, the records for all seasons from 1934-5 onwards were examined. However, because of non-recording of key information, conclusions for Ruakura are based only on the periods 1936-37, 1937-38, and 1939-40 onwards, and for Manawatu-Rangitikei for 1947-48 onwards. The data from Manutuke

TABLE 3. INCIDENCE OF FACIAL ECZEMA

Year	Reported Incidence (Department of Agriculture Annual Report)
	A. Waikato
1937-38*	". . . the most extensive outbreak."
1938-39	". . . comparatively free."
1939-40	No district mention.
1940-41	". . . small isolated outbreaks."
1941-42	"A small number of scattered outbreaks."
1942-43	". . . scattered outbreaks in the Auckland district. Only a very small number of cases in the experimental area at Ruakura. . . ."
1943-44	". . . very few cases of clinical facial eczema . . . but . . . some liver damage in Waikato district."
1944-45	No district mention.
1945-46	No district mention. For North Island as a whole comment " . . . only very few cases . . . observed."
1946-47	No district mention.
1947-48*	"Quite severe outbreaks during February, March, and April."
1948-49*	". . . fairly widespread outbreaks."
1949-50	No district mention.
1950-51*	". . . widespread outbreaks."
1951-52	". . . one (case) in Hamilton."
1952-53	No district mention.
1953-54*	". . . fairly severe outbreaks Cambridge, Te Awamutu—but otherwise light."
1954-55*	". . . a fair number of outbreaks"—this up to 31/3/55. Following year's report covering late autumn 1955 reports heavy losses.
1955-56*	"Number of outbreaks . . . a considerable amount during April."
1956-57	". . . incidence appears to have been relatively light."
1957-58	Isolated outbreaks.

TABLE 3. (Continued)

B. Manawatu-Rangitikei

1947-48	A few isolated outbreaks.
1948-49	"A few flocks were affected in . . . Manawatu."
1949-50	". . . fortunately the disease did not manifest itself clinically."
1950-51*	". . . outbreaks from New Plymouth to Wellington . . . most flocks investigated had small incidence."
1951-52	". . . a few outbreaks in the Manawatu."
1952-53	No district mention.
1953-54	No district mention.
1954-55*	"Incidence relatively slight" (up to 31/3/55). General comment in 1956 report that there were heavy losses in many districts in late autumn of 1955.
1955-56*	General comment that there were heavy losses in many districts, then "Wanganui most affected district but outbreaks occurred in Manawatu."
1956-57	". . . incidence appears to have been relatively light."
1957-58	Warnings issued. Only very isolated occurrence of outbreaks.

* Seasons in which widespread outbreaks considered to have occurred—see Table 6, p. 599.

experimental farm were not used for this part of the work for it is considered to be not sufficiently representative of conditions in the Gisborne district as a whole.

The occurrence and severity of outbreaks of facial eczema in various districts are described in the annual reports of the Department of Agriculture. Extracts from these are quoted in Table 3.

Unpublished data on the dates of commencement of liver damage, as determined from test killings of lambs at Manutuke experimental farm, were kindly made available by Dr. Filmer. As the farm also has its own climatological station, this allowed a more detailed examination of the relationship between weather conditions and the date of occurrence of liver damage in stock grazing at a particular site than was possible with data for the other districts.

PRIOR ASSESSMENT OF A SEASON

It appears that a season can be considered potentially dangerous by the end of November if *either* of two criteria are met. These are:

(a) that the 8 in. soil temperature as measured at 9 a.m. reaches an average level during the month of 62.5°F or over;

or (b) that the main body of moisture in the soil reaches by the end of the month a deficit level of 1½ in. or over.

The soil moisture criterion is a measure of whether there has been drying out of the soil to a considerable depth some time prior to the end of November. Accordingly falls of rain which are sufficient to wet only the surface layers and still leave a zone of dry soil below them are ignored. At Ruakura in 1937-38, for example, the moisture deficit in the main body of soil remained considerably greater than 1½ in., although there were rains in mid and late November which wetted the surface layers.

A more definite judgment can be made by the end of December. It appears that there is a high probablity of subsequent widespread outbreaks if

(1) The average soil temperature at 8 in. exceeds 65°F during December. The data suggest that the higher the average temperature during December, the more the pasture is preconditioned for an outbreak.

(2) There is no "soaking"* rain during December. It is not suggested such rain automatically renders a season safe, but that if the average of the 8in. soil temperature for December is only a degree or so above 65°F, such rains, particularly if spread over several days, will considerably reduce the danger. Also, as was pointed out earlier, where these soil temperatures are well above the normal level for the district, the drying of the soil will be considerably greater than normal. Hence the wetting effects of heavy rain will be less than indicated by the standardised assessment used here.

In the worst seasons at Ruakura and at Ohakea-Palmerston North the above conditions have been met and, in addition, during the latter part of December, approximately the 10th-31st, high grass-minimum temperatures have coincided with rain. Once 8-in. soil temperatures have reached 65°F, any such high grass-minimum temperatures with rain should probably be regarded as precursors to toxicity.

At Manutuke experimental farm, liver damage was found only in seasons in which the December criteria were met (Table 4) but there was one season (1949-50) in which there was liver damage late in the season although the November criteria for possible danger had not been met. In this season both the main soil moisture deficit at the end of the month and the November soil temperatures were fairly near to the levels proposed, and then the December criteria were clearly met. This emphasises that the criteria proposed are a guide for judgment and should not be regarded as stating a rigid boundary between safety and danger.

* The term "soaking" rain refers not to any specific number of inches of rain, but to rains in which *more* water falls than is required to bring the soil, from any previously established soil moisture deficit, up to field capacity. The actual quantity of rain required on any occasion is determined by the soil moisture deficit prior to the rainfall.

Weather Conditions Associated with the Onset of Toxic Periods

From an examination of the weather records for Ohakea and Ruakura, it appears that whereas the general soil moisture and temperature situation, particularly in December, determines how much pastures in a district as a whole have been conditioned for an outbreak, its actual time of commencement is determined mainly by whether or not there is a series of groups of high grass-minimum temperatures with significant rain. If these are absent, few if any outbreaks have occurred in these districts.

It is suggested that the feature of prime importance is the presence of continued warm, moist night conditions around the grass and at the surface of the soil. The criteria chosen for evaluating from the climatological records whether this had occurred were the occurrence of rain of 10 points or over accompanied or immediately followed by two or more successive nights with grass-minimum temperatures of 54°F or over. A high grass-minimum temperature which occurred before rain of 10 points or over was not considered. Also the group of high grass-minimum temperatures must commence at the latest on the night immediately following the last fall of rain of 10 points or over and in any case a night is not taken into consideration if it is more than two days removed from the last fall of at least 10 points of rain. It is of course unwise to interpret criteria such as these absolutely rigidly. For instance, an isolated fall of just 10 points of rain in the middle of a dry spell would not be considered to justify great weight.

The data for Manutuke experimental farm allow a more precise assessment of the relationships between periods of high grass minimum temperatures and toxicity.

The dates of commencement of the period when grass was sufficiently toxic to induce liver damage were assessed from the killing data. In each case the rain that was judged tc initiate the period was accom-

Explanatory Notes—Table 4

(1) The figures indicate the number of consecutive days of grass-minimum temperatures of 54°F or over in each group.

(2) n indicates no liver damage, st slight liver damage, and t severe liver damage.

(3) r indicates that high grass minima were accompanied by a period of rainfall totalling 2.00 in. or over.

(4) * Sequence of grass-minimum temperature and rainfall—

Date Jan.	14	15	16	17	18	19	20	21	22	23
Temperature	58.0	50.9	44.4	48.2	51.2	45.4	55.0	53.4	51.0	55.8
Rainfall	.34	.17	—	.24	.13	.12	.80	.71	.07	—

(5) A line underneath two groups indicates they were separated by only a day or two.

(6) † A period of 11 days of grass minima at 50°F or over occurred after the first rain on 3rd. There was 2.48 in. of rain in the 6 days from the 9th onwards.

(7) 1948-49 omitted from table as grass-minimum readings were incorrect during most of the season,

TABLE 4. Occurrence of Groups of High Grass-minimum Temperature Accompanied by Rain Prior to Liver Damage at Manutuke

	Month					Toxicity Assessment
	Dec.	Jan.	Feb.	Mar.	Apr.	
1957-58			5 n			Toxicity NIL.
1956-57	2r n	4 n	3 t			Toxic period started 3 Feb. and worst over by 21 March. Some slight toxicity after that. "It seems certain toxicity was initiated by the early February rains. From about 12 Feb. toxicity declined. It increased with the advent of rain on 7 March . . . From 21 Mar. temperatures fell and toxicity declined.
1955-56	6 n		4, 2 t			Toxic period 27 Jan. to 13 March with reduced toxicity 8-16 Feb. "Clinical cases occurred on 29 Feb., 1, 6 and 12 Mar. All 4 lambs had been grazing since 27 Jan. . . . With exception of one mildly damaged liver, the livers of all lambs entering paddock on or after 14 March were normal."
1954-55	3r n	2r n	4, 4, 6 n, n, t			Toxic period 26 Feb. to 22 March. "Lambs killed on or before 23 Feb. livers normal. Lambs added on or after 23 March livers normal."
1953-54		2 n	2 n	11r st		Toxic period March 2 to March 22. "Lambs killed up to 2 March all livers normal. Three out of 10 lambs added 16 March showed slight liver damage. Lambs added on or after 23 March all normal."
1950-51		2, 5 n	2 n	3 st		Toxic period Feb. 28 to April 4. "Mild liver damage only occurred in lambs in the usual experiment paddocks of permanent pasture. Lambs killed up to 4 March livers normal. Lambs added on or after 4 April livers normal."
1949-50		2r* n	5 n	2 t		Toxic period March 24-April 6. "Lambs killed up to 27 March livers normal. Lambs added on or after 4 April livers normal. Five clinical cases diagnosed 16 April. Three had been in paddock since 16 Feb., one since 13 Feb., and one since 20 March."
1947-48		2 n			4r, 4 n, n	Toxic period NIL. "Warnings were issued and a few clinical cases did occur in the Gisborne district in early April."
1946-47		2r n	2, 3r† n, st			Toxic period 9-26 Feb. "Some lambs killed on 3 and 10 March including one introduction on 17 Feb. showed mild liver damage. Lambs grazed continually from 18 Jan. killed later than 10 March showed nothing, suggesting resolution had occurred."

panied by or immediately followed by two or more successive nights when the grass-minimum temperatures were 54°F or higher. The data further suggest that this first toxic period was preceded either by two or more groups of high grass-minimum temperatures with rain, or by a single prolonged group of high grass-minimum temperatures with rain (Table 4). The latter situation arose in 1955-56 when 6 days of high grass-minimum temperatures with rain in mid December were followed by a nearly continuous period of 7 days with high grass-minimum temperatures, starting at the end of January. At some time during the latter period the grass was highly toxic. A similar situation occurred that year in the Waikato where the appearance of clinical cases in January occasioned surprise. There, 5 days of high grass-minimum temperatures in mid December were followed by rain on 7 January and with it three nights of high grass-minimum temperatures.

It appears that where a period of high grass-minimum temperatures is accompanied by heavy and prolonged rain, its effectiveness in either inducing toxicity or preparing a pasture for toxicity is reduced (Table 4). A similar effect of heavy rain was noted in considering the preconditioning period, and it has been commented on by others (e.g. Levy and Smallfield 1942; Filmer 1956).

It is also noted that at Manutuke there have been no instances of toxicity arising from periods of high grass-minimum temperatures and rain which occurred more than a fortnight after 8 in. soil temperatures had fallen below 65°F.

There is also a tentative suggestion from the data from the three centres that particularly if a period of high grass-minimum temperatures with rain is followed immediately by one or two sunny days and a cold night, heavy toxicity can be expected from a subsequent period of high grass-minimum temperatures with rain if this occurs almost immediately afterwards. The initial toxic peroids during 1956 at Manutuke and during 1958 at Massey College (Butler 1958) are examples of this. There was a similar situation during February 1938 in the Waikato.

In addition to the readings taken at the climatological stations at Wanganui and Ohakea, daily recordings of grass-minimum temperatures and of rainfall were taken at a number of sites in the Wanganui district during the summer and autumn of 1957-58. All sites were under 500 ft elevation but some were on hills, others in valleys and others surrounded by flat land with or without buildings close by. It was apparent that during February and March—the main outbreak months—there was a considerable similarity between the readings at various sites on occasions when grass-minimum temperatures reached 54°F or over and there was significant rain. The more important site to site variability was in the presence or absence of significant rain. However, in any district there are generally warm sheltered areas reputed to get outbreaks frequently and early. An important feature of their environment may be not only early warming of the soil but also a trend for periods of high grass-minimum temperatures to occur with rains during December and January when temperatures on the more exposed areas do not reach what are suggested to be critical levels.

Weather Systems

It is to be expected that periods of high grass-minimum temperatures in combination with rainfall will occur only when the air-mass over the area concerned is unusually warm and moist. The influx of warm moist air over eczema-prone areas of the North Island can occur as a result of a variety of meteorological situations. In some cases the air is of recent tropical origin, in others it is polar air which has been warmed during a long passage across sub-tropical waters.

Using data from Manutuke for the period November 1946 to April 1956, 37 such periods were selected. The weather systems associated with these conditions were then grouped according to the following classification (Table 5). The grouping is necessarily rather rough, chiefly because of changes in type which may occur within each period.

TABLE 5. METEOROLOGICAL SITUATIONS WITH GROUPS OF HIGH GRASS-MINIMUM TEMPERATURES (54° AND OVER) ACCOMPANIED BY RAIN AT MANUTUKE (NOVEMBER-APRIL INCLUSIVE)

Type I	Type IIa	Type IIb	Type III	Type IV
	13-16/3/48	**2-4/3/54**	**25-26/3/50**	20-21/4/56
14-15/1/47	31/3-4/4/48	4-7/2/55		
9-10/2/47		10-12/2/55		
23-24/3/47				
20-22/4/47	20-23/1/50	**17-18/2/56**		
	9-12/2/50	**28-29/2/56**		
16-17/1/48				
28/2-1/3/51		4-6/3/56		
6-10/2/52	30/12-3/1/51			
15-16/3/52	8-9/2/51			
23-24/1/54	14-17/1/52			
	2-3/4/54			
5-12/3/54				
	21-22/4/54			
11-15/3/55	21-23/12/54			
28-31/1/56	17-18/1/55			
3-4/2/56	**26/2-1/3/55**			
10-11/3/56	21-22/4/55			
5-10/4/56	14-19/12/55			
Totals 15	14	6	1	1
Within Toxic Periods				
7	1	4	1	—

Note.—The groups in bold type are those associated with definite occurrence of facial eczema in lambs at Manutuke, i.e. within the toxic periods stated in Table 4.

Type I. Tropical cyclone or deep depression approaching from north or north-west to pass over or close to the North Island.

Type IIa. Low pressure centre or marked trough over, or to the north of Gisborne; anticyclone or ridge across southern New Zealand.

Type IIb. Weak quasi-stationary front or trough over, or to north of Gisborne; anticyclone or ridge over southern New Zealand. (In this situation rain is uncertain and often difficult to forecast correctly.)

Type III. Cold front moving northwards accompanied by rain in eastern districts of the North Island and followed by a cool southerly change; pressure high over South Island or South Tasman Sea. (Because of the cool change, toxicity is not expected; but this situation may develop into a Type IIb or, if a wave should form on the front, into Type IIa. When such development occurs, the drop in tempera-

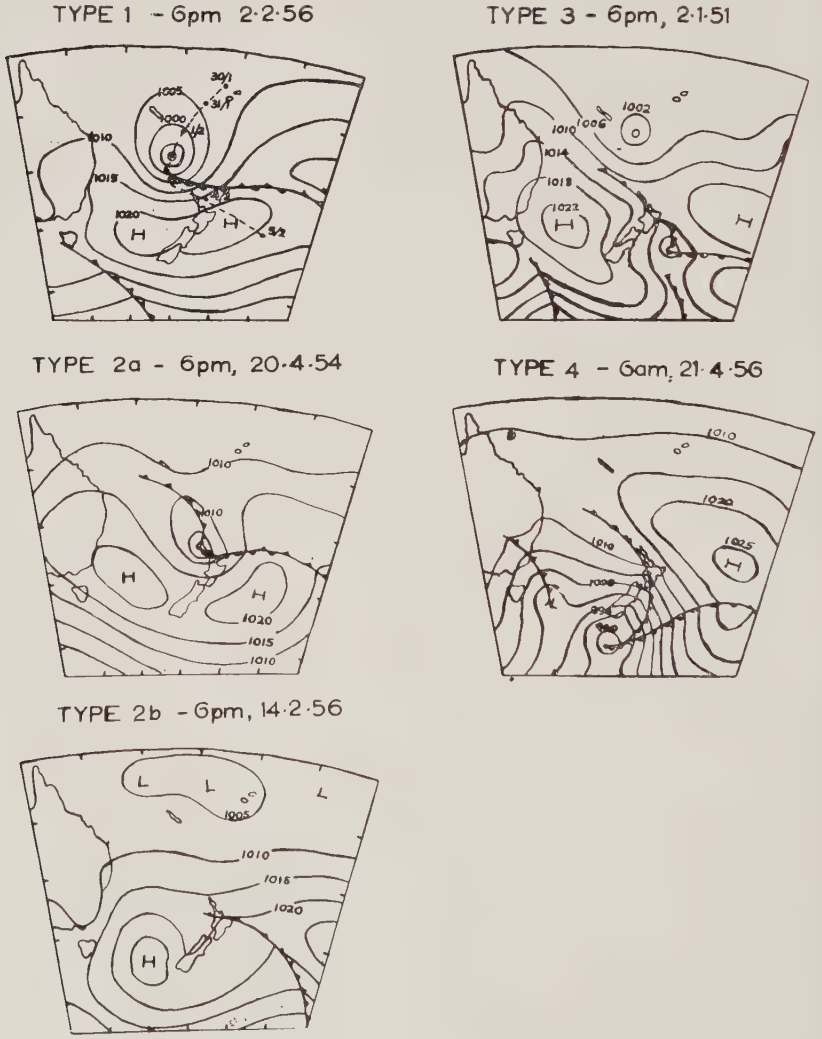


Fig. 2.—Weather maps selected as typical examples of the weather systems associated with periods of high grass-minimum temperatures and rain.

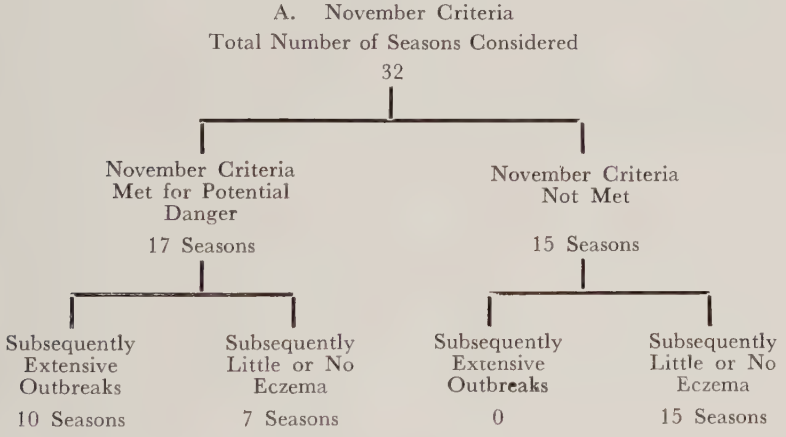
ture with the southerly change may be slight and of short duration to be followed by warm rains soon afterwards.)

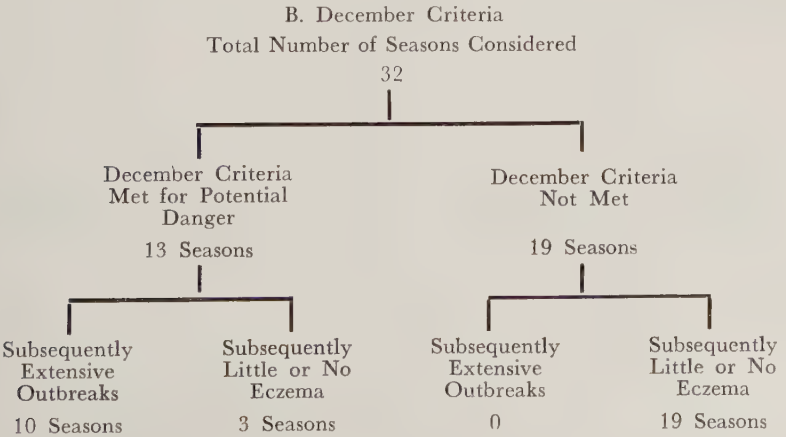
Type IV. Meridional front associated with a deep depression to the south. (The passage of a meridional front eastwards across the Gisborne district usually brings little or no rain to Manutuke, so this type is rarely effective there.)

Weather maps selected as typical examples of the above types of situation are given in Fig. 2.

The importance of favourable antecedent conditions is well illustrated by the data in Table 5. All of the toxic periods known to have

TABLE 6. RELATIONSHIPS BETWEEN THE NOVEMBER AND DECEMBER PREDICTION CRITERIA AT RUAKURA, AND AT OHAKEA-PALMERSTON NORTH, AND THE OCCURRENCE OF WIDESPREAD OUTBREAKS OF FACIAL ECZEMA IN THE FOLLOWING AUTUMN IN THE DISTRICTS SURROUNDING THE RECORDING STATIONS





occurred at Manutuke during the seasons considered are represented in the table, yet they amount to roughly only one in three of the total number of periods with rain and high grass-minimum temperatures. It is also worthy of note that the toxic periods are not associated with any one type of meteorological situation, although the majority occur with the approach of a depression (or cyclone) from the north or north-west (Type I).

Fig. 3.—Moisture and temperature conditions in soil and pasture during seasons which are selected as illustrative of the main features of the weather conditions suggested as related to incidence of facial eczema.

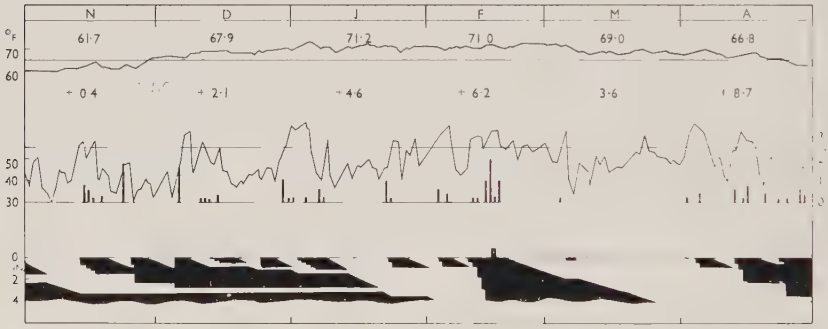


Fig. 3A. Ruakura, 1937-38

A season in which the main soil moisture deficit was greater than 1½ inches at the end of November and then the average of the 8 in. soil temperatures in December was over 65°F and there were no soaking rains in that month. Also there was a period of high grass-minimum temperatures with rain during December and several periods occurred later in the season. Severe eczema outbreaks.

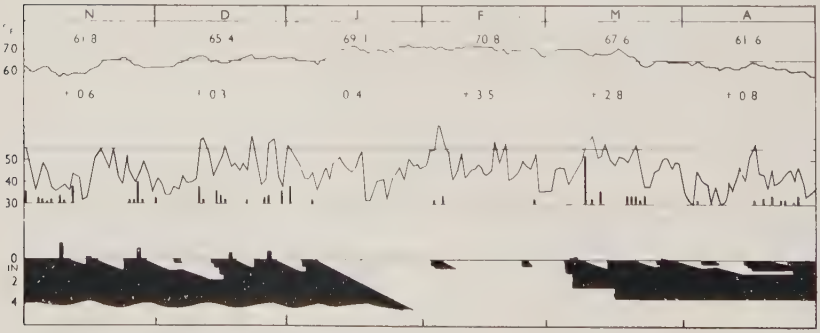


Fig. 3B. Ruakura, 1956-57

The main soil moisture deficit at the end of November was much less than 1½ inches and although the average of the soil temperature at 8 in. for December was over 65°F, there was soaking rain in that month. There were several groups of high grass-minimum temperatures with rain during the season. Little eczema occurred.

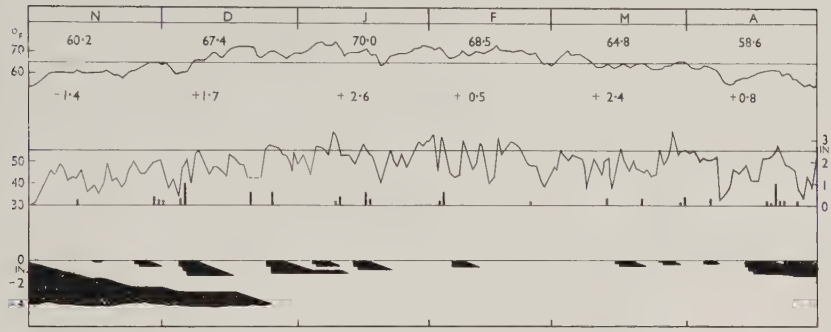


Fig. 3C. Ohakea, 1947-48

A season in which the main soil moisture deficit was greater than 1½ inches at the end of November and then the average for the 8 in. soil temperatures in December was over 65°F and there was no soaking rain during that month. There were three groups of high grass-minimum temperatures with rain early in the season, namely on 26-27 December, 9-10 January, and 16-17 January. Conditions were extremely dry during late January, February and March, and a further group of high grass-minimum temperatures with rain did not occur until 30th March.

Isolated minor outbreaks.

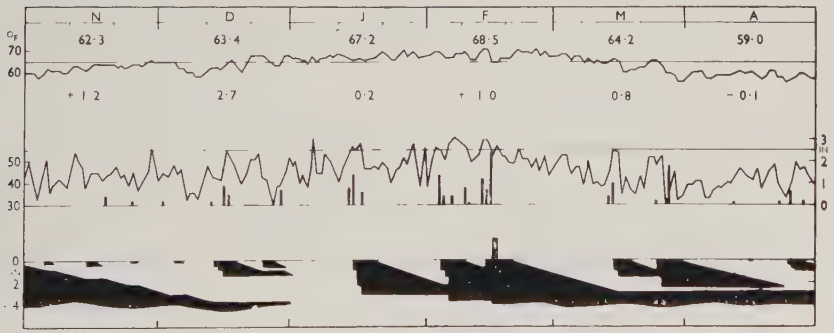


Fig. 3D. Manutuke, 1951-52

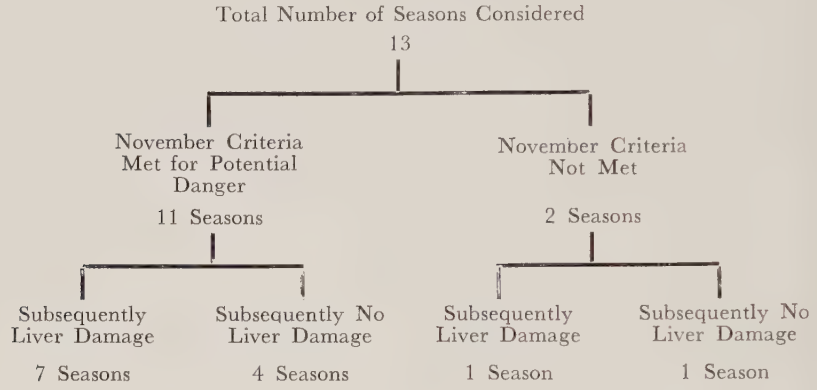
The main soil moisture deficit at the end of November was greater than 1½ inches, and no soaking rain occurred in December, but the average of the soil temperatures at 8 in. for December was under 65°F. Several groups of high grass-minimum temperatures with rain occurred during the season but in some cases the falls of rain concerned were over 2 in. in amount.

No liver damage found at Manutuke experimental farm.

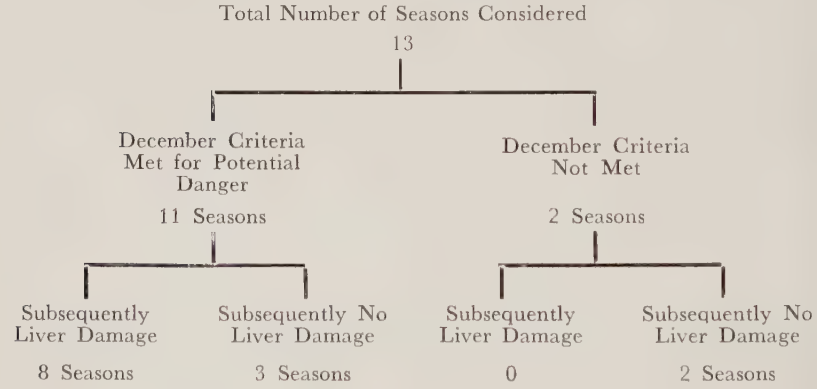
The meteorological situations in which warm rains develop in other North Island districts have not been examined in detail; but it is obvious that the classification given which is appropriate to the Gisborne district will have only limited application to, say, the Rangitikei dis-

TABLE 7. Relationships between the November and December Criteria of Weather Conditions at Manutuke and the Occurrence of Liver Damage in Lambs Grazing on the Test Areas in the Experimental Farm During the Following Autumn

A. November Criteria



B. December Criteria



trict. For instance, many of the Types IIb and III situations produce little if any rain in the Rangitikei district. Both here and in the Waikato district warm rains from north-west in summer are much more common than in Gisborne where the high ranges to the west cut off most of the rains from this quarter.

Discussion

The conclusions presented here are a quantitative evaluation of soil moisture and temperature conditions and of weather situations preceding and accompanying outbreaks of facial eczema. The information may assist the investigation of the field ecology of the fungus now known to be associated with the disease. Further it may assist judgments as to the degree of danger developing in a district.

A summary of the relationship between eczema outbreaks and the soil temperature and soil moisture criteria suggested for judging potentialities for outbreaks at the end of November and December is set out in Table 6 for the Waikato and Manawatu-Rangitikei districts. Table 7 states the relationship between these criteria and the occurrence of liver damage with test animals at Manutuke experimental farm. Examples of the use of the various criteria for judging the course of a season are given in Fig. 3 and its explanatory notes.

Absence of precise information from the other districts as to when liver damage first occurred makes it impracticable to check accurately the suggestions made by the Manutuke data as to the relationship between periods of high grass-minimum temperatures with rain and toxicity. However there are a number of seasons in which information from various sources gives an indication of month of appearance of liver damage or visible lesions, and in some cases the rains concerned can be identified. Although it must be clearly understood that even in these seasons important liver damage may have occurred some time before trouble was noticed, there are no instances known to the authors of toxicity to grazing animals being reported earlier than expected by the criteria suggested from Manutuke data. It is of interest that this holds not only for the seasons in which extensive outbreaks occurred following a suitable conditioning period in spring and early summer, but also it appears to hold for such isolated outbreaks as occurred in seasons with unfavourable preliminary conditions.

The two sets of criteria suggested by the data are complementary to each other. On the one hand the spring and early summer conditions indicate the degree of danger to be expected subsequently in a season for a district as a whole. On the other hand the occurrence of rainfall with groups of high grass-minimum temperatures appears to give an indication of the time before which liver damage would not be expected to commence.

ACKNOWLEDGEMENTS

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REFERENCES

Butler, G. W. 1958: A Progress Report on a Ryegrass Strain Trial with Particular Reference to Facial Eczema. *Massey agric. Coll. Sheepfmg. Annu. 1958.* p. 203.

Cooper, E. R.; Walker, D. 1940: Climatic Factors Relating to Outbreaks of Facial Eczema in New Zealand. *N.Z. J. Sci. Tech. A22:* 30.

Filmer, J. F. 1956: Facial Eczema Research. *Massey agric. Coll. Sheepfmg. Annu. 1956.* p. 11.

————1957: Losses from Facial Eczema Can be Prevented. *N.Z. Dep. Agric. Bull. 388.*

Levy, E. B.; Smallfield, P. W. 1942: Photosensitivity Disease in New Zealand. II. Facial Eczema. The Influence of Soil, Climate, Pasture Composition and Management. *N.Z. J. Sci. Tech. A24:* 198.

McMeekan, C. P. 1956: The Control of Facial Eczema in Sheep. *Massey agric. Coll. Sheepfmg. Annu. 1956,* p. 21.

Mitchell, K. J. 1957: Discussion on Paper by G. W. Butler and A. L. Rae. A Progress Report on a Ryegrass Strain Trial with Special Reference to Hogget Ill-thrift and Facial Eczema. *Ibid. 1957,* p. 188.

Mitchell, K. J.; Closs, R. L. 1958: Loss of Moisture from Vegetation. *Nature 181:* 1619.

Simmons, Pamela E. 1951: Climate and Facial Eczema in New Zealand: II. *N.Z. J. Sci. Tech. A33:* 53.

Simpson, J. E. V.; Sinclair, D. P.; Swan, J. B.; Filmer, J. F. 1957: Photosensitivity Diseases in New Zealand. XI. Collection and Preservation of Pasture that Produces Facial Eczema. *Ibid. A38:* 947.

Thornton, R. H.; Percival, J. C. 1959: A Hepatotoxin from *Sporidesmium bakeri* capable of producing Facial Eczema Diseases in Sheep. *Nature, Lond., 183:* 63.

POLLEN STERILITY IN PUKEKOHE LONGKEEPER ONIONS

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Summary

Tests of the progeny of bulbs of Pukekohe Longkeeper onion indicate the presence of the cytoplasmic factor S for male- or pollen-sterility as well as the recessive factor *ms* for this condition. Additional tests of small material of two other related New Zealand varieties indicate the two factors in common.

There is some comment on the favourable influence of this condition on any projected hybrid onion programme for New Zealand.

Introduction

The Pukekohe Longkeeper variety of onion (*Allium cepa* L.) which originated in the Pukekohe district near Auckland is said to have been selected from the Straw Spanish variety. It is grown commercially throughout New Zealand, and although other varieties have been tried, none has supplanted this variety, except in limited areas where Rangitikei Red—reported to be a further selection from Straw Spanish or its derivative Pukekohe Longkeeper —is grown. Its superior keeping quality is its main attribute under New Zealand conditions. Yields of other varieties, and especially the new U.S. hybrid types, often surpass this variety (Yen in press), but only Rangitikei Red approaches it in the ability to overwinter in storage. It is the opinion of commercial growers here that new varieties cannot be expected to supersede Pukekohe Longkeeper unless they have its good keeping quality, so that any programme of onion improvement in New Zealand would probably need to include the local variety in parental material.

The use of high-yielding F1 hybrids is a means of onion improvement which has met with success in the United States. The discovery of male sterility in the variety Italian Red by Jones and Emsweller (1937) and the elucidation of its genetics by Jones and Clarke (1943) made possible the subsequent development of methods of producing F1 seed commercially. This sterility is conditioned by the recessive gene *ms* which, when homozygous and associated with the cytoplasmic factor S, produces the sterile phenotype. All other combinations of genotype and 'cytotype' are phenotypically fertile. The S *ms ms* combination is termed the A line and the fertile N *ms ms* which is necessary for the maintenance of the sterile line is termed the B line.

In surveying the possibilities here of an onion improvement programme to produce hybrids with the keeping qualities of Pukekohe Longkeeper and the higher yield and evenness of the American hybrids, it was necessary to test the local variety for the presence of genic and cytoplasmic sterility determinants. These tests, begun in 1954, are described here.

Materials and Methods

The following material was tested in this study:

(a) 6 bulbs of Pukekohe Longkeeper (designated PLK hereafter), derived from 7 parent bulbs of commercial PLK, selected for resistance to white rot (*Sclerotium cepivorum* Berk.) and for keeping quality.

(b) 6 bulbs of PLK, selected from commercial PLK for keeping quality.

(c) 3 bulbs of Straw Spanish (SSp), from commercial stock.

(d) 3 bulbs of Rangitikei Red (RR), commercial stock.

Bulbs of A line were grown for these tests from seed of the line 2264A of the U.S. Department of Agriculture.

In testing the material for presence of the male sterility gene, the test used by Little *et al.* (1944) in a survey of 29 varieties was applied. Bulbs of A line as female parents pair-crossed with test bulbs give progenies in which the genotype of the latter can be determined. The pollen parent cannot of course be S *ms ms*. If both male-sterile and male-fertile plants appear in the progeny of crosses between A and the pollen parent, its genotype is *Ms ms*. All male-sterile progeny indicates *ms ms*. This test is called the A test in this paper.

The pollen parents were also selfed, using separate flower heads in A-tested plants, so that any genotypes *Ms ms* with S cytoplasm would be revealed in the progeny test.

With this series of tests, plants of the constitutions N *Ms Ms* and S *Ms Ms* cannot be distinguished from one another, but all other genotypes and cytoypes can be determined (Table 1).

TABLE 1. The Determination of Male-sterility Genotype and Cytotype of Onions by Testing Pollen in Progeny

Parent			Phentoypes of Progeny in Tests	
Cytotype	Genotype		Self Test	A Test
N	*Ms*	*Ms*	Fertile	Fertile
N	*Ms*	*ms*	Fertile	1 Fertile 1 Sterile
N	*ms*	*ms*	Fertile	Sterile
S	*Ms*	*Ms*	Fertile	Fertile
S	*Ms*	*ms*	3 Fertile 1 Sterile	1 Fertile 1 Sterile
S	*ms*	*ms*	—	—

In the summer 1955-56, plants from bulbs grown in the previous summer and stored over the winter were pollinated in the greenhouse. When flower heads of the test plants were well formed, each individual head was enclosed in a wire cage covered with cloth gauze. Heads for A test were combined with A heads in one cage just before flower

opening when pollen from the latter was examined for pollen sterility. Self-test heads were isolated in individual cages. At flower opening, flies free from pollen were introduced into all cages to effect cross- or self-pollination. Flies were replenished as long as the flowers bloomed. These procedures as well as those of raising flies have been described by Jones and Emsweller (1933).

In the 1956-57 season the seed from these test pollinations was spring sown to produce bulbs for overwintering and transplanting for flowering in the field in August 1957. Where possible, 54 bulbs of each test were planted in field plots. One hundred and eight PLK and 54 RR bulbs from commercial seed were also planted.

Classification of progeny and the additional commercial bulbs was based on the separation of sterile from fertile by the appearance of anthers prior to dehiscence. Peterson and Foskett (1953) described another appearance at this stage of sterile individuals in the Scott County Globe variety as having a translucent green colour. Three or four anthers from each plant were then smeared on a slide stained with aceto-carmine and microscopically examined. Between 200 and 400 pollen grains were examined from each plant. There was more variation in the bulbs classified as sterile by visual examination than was obtained by Peterson and Foskett. In the pollen examinations, the range of percentage of fertile pollen varied from 0% to 80% as compared with 0% to 14% in the quoted authors' study. This disparity may possibly be accounted for by the fact that PLK is extremely variable in the anther colour character, having yellow and green anthers which makes the visual classification on the basis of colour difficult. Thus the results presented here are based on pollen counts.

The separation of sterility-fertility based on percentage of viable-appearing pollen was difficult to set, since there was a continuous variation over the segregating progeny and within each progeny. (Peterson and Foskett's visually classified "intermediate" plants show a range from 0–100% in 13 plants.) It was decided to attempt this separation in terms of functional sterility. After pollen classification, 21 plants varying from 0–95% viable-appearing pollen which grew further flower heads were subjects of a pollinating test on sterile A-genotype heads. This was effected by removing the new stalks prior to flower opening, placing in bottles filled with tap water, and transferring to where A bulbs at the same stage of growth were available. The pair crosses were then performed as for the original A tests.

On the basis of this test (Table 2), it was decided to classify as sterile, in A and self tests, bulbs whose flower heads showed less than 10% viable-appearing pollen.

RESULTS

Table 3 gives the results of the progeny tests of all the material, and the probable genotypes and cytotypes deduced from these. In A test, the progenies from crosses with ten of the PLK plants showed the presence of the *ms* allele, in each case in the heterozygous condition,

TABLE 2. PERCENTAGE FLOWERS OF A PLANTS PRODUCING SEED ON POLLINATION WITH FLOWERS OF DETERMINED PERCENTAGE VIABLE-APPEARING POLLEN

% Viable-appearing Pollen	No. Plants Tested	% Flowers of A Producing Seed
0	6	ALL 0
5	6	0, 20, 5, 1, 1, 0
10	4	50, 7, 65, 10
20	3	5, 95, 75
90	1	90
95	1	75

TABLE 3. THE PROBABLE GENOTYPE AND CYTOTYPE OF TESTED ONION PLANTS BASED ON ANALYSIS OF POLLEN OF THEIR PROGENY

Test Plant No.*	No. Progeny Classed Fertile (F) or Sterile (S) in Tests				Probable Cytotype and Genotype
	Self		A × . . .		
	F	S	F	S	
PLK 1	27	26	16	38	S *Ms ms*
PLK 2	37	17	—		S *Ms ms*
PLK 3	38	16	31	23	S *Ms ms*
PLK 4	36	16	34	20	S *Ms ms*
PLK 5	4	0	29	22	S *Ms ms*
PLK 6	54	0	29	19	N *Ms ms*
PLK 7	46	0	54	0	N or S *Ms Ms*
PLK 8	9	0	41	13	N *Ms ms*
PLK 9	53	0	51	0	N or S *Ms Ms*
PLK 10	47	4	33	18	S *Ms ms*
PLK 11	54	0	44	6	N *Ms ms*
PLK 12	3	2	24	30	S *Ms ms*
S Sp 1	34	0	2	0	N or S *Ms Ms*
S Sp 2	6	0	53	0	N or S *Ms Ms*
S Sp 3	40	13	48	6	S *Ms ms*
RR 1	30	0	53	0	N or S *Ms Ms*
RR 2	38	4	5	0	S *Ms ms*

* PLK 1–6 selected for resistance to white rot, the remainder for keeping quality.

The selfing test in conjunction with the A test suggests that nine of the twelve heterozygotes also carry the cytoplasmic factor S on which the genes depend for phenotypic expression. Five of these nine are descended from seven bulbs selected for resistance to white rot.

A check on the *Ms ms* genotype plant progenies for conformity to the 3 : 1 ratio in the self test and the 1 : 1 in the A test is given in Table 4. In compiling the data for these tests all *Ms ms* results were included in the case of the A test, but only those with S cytoplasm

could be used in the self test. In the self test the data show conformity with the 3 : 1 ratio, although reference to Table 3 shows that progenies of PLK1 and 10 and RR2 deviate from the ratio. Data from the A test show a poor fit to the 1 : 1 ratio, deviations from expectation being accounted for by PLK8 and 11 and SSp3.

TABLE 4. DISTRIBUTIONS OF FERTILE : STERILE IN TESTS OF PROGENIES OF ONION PLANTS. HETEROZYGOUS FOR MALE-STERILE GENE

Test	Expected Ratio	Total Plants	Progeny		χ^2	P
			Fertile	Sterile		
Self	3 : 1	368	270	98	0.522	0.50–0.30
A	1 : 1	529	334	195	36.524	0.01

These deviations may be partly attributed to the arbitrary standard which was set up to separate progeny test plants into fertile/sterile categories. Re-examination, at an advanced stage of flowering, of some individual plants which had shown mixed (fertile- and sterile-appearing) pollen, showed some with a proportion of grains still stainable, but with nuclei diffusing and clearing cytoplasm.

Fig. 1, a photomicrograph, shows what appears to be two stages of this degeneration as well as a sterile unstained grain among viable-appearing pollen. It is possible therefore that observations made at a later stage might have increased the number of plants classed as sterile. Deviations from expected ratios of progeny from known parent genotypes are recorded in the literature. Jones and Clarke (1943) state that high greenhouse temperatures (unspecified) reduce the percentage of viable pollen in male-fertile plants and that this probably accounts for the excess of recorded male-sterile plants in expected 3 fertile : 1 sterile progeny ratios from selfing S *Ms ms* genotypes in their experiments. Barham and Munger (1950), however, reporting a temperature-controlled experiment on seven S *ms ms* inbred lines show that in the range 75°–85°F between 0.2% and 16% of microspores reach first post-meiotic division, and a low percentage 0 to 0.26% of viable-appearing pollen was recorded. At 50°–60°F no fertility of pollen was shown in any line. At 80°–95°F, percentages of 3–16 microspores reaching post-meiotic division were recorded, but only one line in five tested showed 0.05% viable-appearing pollen.

In the summer of 1955, of 14 bulbs of 2264A line (S *ms ms*) grown in the greenhouse here, two flowers tested gave 2 viable-appearing pollen grains out of 301, and 1 out of 356. On selfing, neither produced seed. Peterson (1958) demonstrated a similar male-sterility system dependent on cytoplasm for genic expression in *Capsicum* showing a reduction in male fertility with high temperatures.

With the phenotypic expression of this genetic situation being sensitive to temperature at pollen formation, this might have constituted a

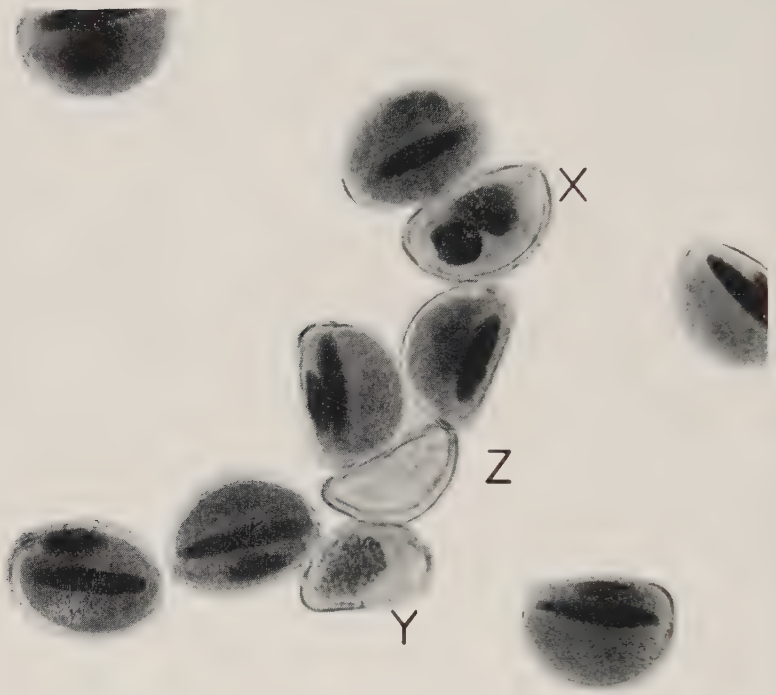

Fig. 1.—Photomicrograph of an aceto-carmine smear preparation from a plant from A test (2264A × PLK) at advanced flowering stage, showing fertile-appearing grains, one grain X with diffuse nucleus, clearing cytoplasm, grain Y with nucleus degenerating, and grain Z, sterile.

Photo: S. A. Rumsey

further limit to accurate phenotype classification, and thus may account for the odd ratios in this experiment. The air temperatures during the period December 1957 to January 1958 in which pollen formation occurred varied between 40°F and 83°F.

Barham and Munger (1950) found that *Ms ms* genotype with S cytoplasm gave a significantly lower percentage of fertile-appearing pollen than N *Ms Ms* and N *ms ms*, and attribute this to the influence of the S cytoplasm. In the present material *S Ms ms* genotype was compared directly with N *Ms ms* on the basis of the mean percentage viable-appearing pollen in the progeny. Table 5 gives the data from PLK progeny tests of plants 1, 2, 3, 4, 5, 10, 12 as S *Ms ms* type and plants 6, 8, 11 as N *Ms ms*. Although progenies in both tests from S cytotype parents show lower mean percentage viable-appearing pollen than those from N cytotype parents, the differences are non-significant: standard errors of means are high in all categories since there was marked variation in the percentage of viable pollen in tested plants. This variation was common to all progenies. The limitation of this experiment in the classification of pollen already referred to has to be

TABLE 5. PERCENTAGE OF VIABLE-APPEARING POLLEN IN THE FERTILE PROGENY OF S *Ms ms* AND N *Ms ms* IN A AND SELF TESTS IN PLK ONIONS

Parent Type	Mean Percentage Viable-appearing Pollen in Progeny	
	From Self Test	From A Test
S *Ms ms*	74.2 S.E. Mean 10.31	68.1 S.E. Mean 13.14
N *Ms ms*	86.0 S.E. Mean 5.57	82.8 S.E. Mean 8.30

taken into account. In Table 6 the distribution according to viable-appearing pollen percentage is shown of all the progenies of *Ms ms* genotypes of PLK origin.

Tests of the PLK commercial bulbs yielded one with 100% sterile pollen, while another gave 2% viable-appearing counts. The Rangitikei Red commercial bulbs gave no pollen sterility, and only one which might be called intermediate. These distributions are included in Table 6.

TABLE 6. DISTRIBUTION OF PLANTS IN PROGENY TEST (PLK MATERIAL) CLASSED AS FERTILE OR STERILE ON BASIS OF PERCENTAGE VIABLE-APPEARING POLLEN: ALSO DISTRIBUTION IN COMMERCIAL VARIETIES

% Viable-appearing Pollen	No. Plants Classed as		No. Plants in Commercial Varieties	
	Sterile	Fertile	PLK	RR
0	286	—	1	—
1– 9	47	—	1	—
10–29	—	61	—	—
30–49	—	37	2	1
50–69	—	63	8	—
70–89	—	142	16	12
90–99	—	287	79	37

DISCUSSION

Since Jones and Emsweller (1937) described pollen sterility in Italian Red 13-35, only one instance of naturally occurring pollen sterility of this type has been recorded in onions (Peterson and Foskett 1953). This was found in the variety Scott County Globe.

From the available evidence, it appears that the same sterility occurs in the Pukekohe Longkeeper variety, which has no known connection with the above two varieties. It is noteworthy that in the re-

lated varieties Rangitikei Red and Straw Spanish there is some indication of the same situation. Little *et al.* (1944) have demonstrated that the *ms* gene occurs in most varieties, and it has been recorded in the only bulb of PLK tested in a recent survey of some world varieties by Davis (1957). The results of the selfing tests leave little doubt of the presence of the cytoplasmic factor, and this is supported by the occurrence of pollen sterility in the commercial PLK bulbs tested.

The presence of both factors, cytoplasmic and genetic, for pollen sterility in the local variety Pukekohe Longkeeper will be valuable to the planned breeding of hybrid onions. The A (S *ms ms*) and B (N *ms ms*) lines of Pukekohe Longkeeper required for such a procedure are obtained easily without crossing out of the variety and subsequent backcrossing to recover its characteristics. Thus any hybrid programme involving Pukekohe Longkeeper as a parent can be expedited.

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References

Barham, W. S.; Munger, H. M. 1950: The Stability of Male Sterility in Onions. *Proc. Amer. Soc. hort. Sci. 56:* 401-9.

Davis, E. W. 1957: The Distribution of the Male-sterility Gene in Onion. *Ibid. 70:* 316-8.

Jones, H. A.; Clarke, A. E. 1943: Inheritance of Male Sterility in the Onion and the Production of Hybrid Seed. *Proc. Amer. Soc. hort. Sci. 43:* 189-94.

Jones, H. A.; Emsweller, S. L. 1933: Methods of Breeding Onions. *Hilgardia 7:* 625-42.

————1937: A Male-sterile Onion. *Proc. Amer. Soc. hort. Sci. 34:* 582-5.

Little, T. M.; Jones, H. A.; Clarke, A. E. 1944: The Distribution of the Male-sterility Gene in Varieties of Onions. *Herbertia 11:* 310-12.

Peterson, C. E.; Foskett, R. L. 1953: Occurrence of Pollen Sterility in Seed Fields of Scott County Globe Onions. *Proc. Amer. Soc. hort. Sci. 62:* 443-8.

Peterson, P. A. 1958: Cytoplasmically Inherted Male Sterility in *Capsicum*. *Amer. Nat. 92, No. 863:* 111-9.

Yen, D. E. (in press): American Onion Hybrids in New Zealand. *N.Z. Commercial Grower.*

INCIDENCE AND PARASITISM OF INSECT PESTS OF CRUCIFEROUS CROPS IN THE NORTH ISLAND—EVALUATION OF DATA, 1955-58 SEASONS

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Summary

Damage to crucifer crops in Hawke's Bay, Wairarapa, Manawatu, Rangitikei, and Taranaki, during 1957–58, was extremely slight and in most cases confined to margins of crops.

Virus disease (symptoms of which are described) caused heavy mortality of white butterfly, *Pieris rapae* (L.), during the latter part of the season, when parasitism by *Pteromalus puparum* also reached a high level. The larval parasite *Apanteles glomeratus* (L.) appears to exercise no control.

The diamond-back moth, *Plutella maculipennis* Curtis, was effectively controlled by the parasites *Angitia cerophaga* (Gravenhorst) and *Diadromus collaris* (Gravenhorst), particularly the former. A fungus is also effective in the autumn.

Populations of the cabbage aphid *Brevicoryne brassicae* (L.) were very small in all districts.

Introduction

During the 1955–56 and 1956–57 seasons, field surveys were carried out in the main crucifer-growing areas of the North Island (Todd 1957, 1958) to ascertain the incidence and parasitism of insect pests of cruciferous crops growing in these areas.

Crops growing in Hawke's Bay, Wairarapa, and Manawatu were under examination during the summer of 1955–56, and for the 1956–57 season the survey was extended to the Rangitikei and Taranaki districts as well.

The data so far obtained from these two surveys indicate clearly the importance of the virus disease as a controlling agent of the white butterfly, *Pieris rapae* (L.). No larval parasites, *Apanteles glomeratus* (L.), have been recovered, but the pupal parasite, *Pteromalus puparum* (L.), appears to be highly efficient, particularly during the latter part of the season.

In most cases incidence of the diamond-back moth, *Plutella maculipennis* Curtis, was extremely low, and, in general, parasitism of this pest by the larval parasite, *Angitia cerophaga* (Gravenhorst), was consistently high. Only one case of significant crop damage by the cabbage aphid, *Brevicoryne brassicae* (L.) was recorded.

A third season's survey was undertaken during the summer of 1957–58. Results of this, which was again carried out in Hawke's Bay, Wairarapa, Manawatu, Rangitikei, and Taranaki districts, are given in the following account.

TABLE 1. Collection of *P. rapae* Larvae in Field 1957–58

Group	Crop	Variety‡	Date Collected	Duration of Collection (min)	No. Collected	Classification of Crop Damage*	Group	Crop	Variety‡	Date Collected	Duration of Collection (min)	No. Collected	Classification of Crop Damage*
1	A	C	20.2.58	20	33	1	7	A	C	28.2.58	10	16	1
	B	C	,,	,,	36	2		B	R	,,	,,	0	1
	C	C	,,	,,	11	1		C	C	,,	,,	7	1
	D	C	,,	,,	10	1		D	C, S	,,	,,	52	1
	E	C	,,	,,	10	1		E	C	,,	,,	6	1
2	A	C	19.2.58	20	53	2	8	A	C	28.2.58	10	7	1
	B	C	,,	,,	28	2		B	C	,,	,,	31	1
	C	C	,,	,,	33	2		C	C	,,	,,	11	1
	D	C	20.2.58	10	0	1		D	C	,,	,,	7	1
	E	C	19.2.58	,,	106	3		E	C	,,	,,	2	1
3	A	C, T	21.2.58	20	5	1	9	A	C	27.2.58	10	3	1
	B	C	,,	,,	75	3		B	C, S	,,	,,	7	1
	C	C	20.2.58	,,	63	3		C	C	,,	,,	5	1
	D	C	,,	,,	16	1		D	C	,,	,,	0	1
	E	C	21.2.58	,,	43	1		E	S	,,	,,	11	1
4	A	C	21.2.58	10	4	1	10	A	C	27.2.58	10	3	1
	B	C	,,	,,	3	1		B	C, S	,,	,,	6	1
	C	C, S	,,	,,	1	1		C	S	,,	,,	7	1
	D	C	,,	,,	0	1		D	C, S	,,	,,	28	1
	E	C	,,	,,	0	1		E	C	26.2.58	,,	23	1

5	A	C	24.2.58	10	1	1	11	A	C	26.2.58	10	16	1
	B	C	„	„	4	1		B	C	„	„	2	1
	C	C	„	„	1	1		C	C, S	„	„	6	1
	D	C, T	„	„	3	1		D	S	„	„	15	1
	E	C	„	„	0	1		E	C, S	„	„	2	1
6	A	C	24.2.58	10	67	1	12	A	C, S	26.2.58	10	3	1
	B	C	„	„	21	1		B	C, S	„	„	2	1
	C	C	„	„	29	1		C	C, S	„	„	1	1
	D	C	„	„	27	1		D	S	„	„	1	1
	E	R	„	„	8	1		E	C, S	„	„	8	1

No parasitism by *A. glomeratus* was found in the survey.

Where virus infection was present throughout a crop, the figures obtained were not for total population, but only for apparently healthy larvae.

* 1. nil — injury too slight to be of any consequence.

2. slight — injury noticeable, but not appreciably affecting plants.

3. moderate — injury conspicuous, plants partially defoliated.

4. severe — injury conspicuous, plants completely defoliated.

Assessment of crop damage is based on injury to plants growing in the marginal portion of the crop only.

‡ C = Chou moellier; R = Rape; S = Swede; T = Turnip.

Methods

During the 1957–58 season, field collections of white butterfly and diamond-back moth were made from 60 individual crops. The methods and techniques used for collecting and handling the material were the same as those employed during the two preceding seasons (Todd 1957). This was considered necessary to attain some degree of uniformity throughout the whole series of investigations. With few exceptions, no difficulty was experienced in locating crops growing either in the same field, or within half a mile from those selected for the previous season's work.

Where butterfly damage is reported, it refers to the marginal part of the crop only.

The areas surveyed during the 1957–58 season, and the distribution of the groups of crops from which collections were made, are the same as in 1956–57 (Todd 1958, p.849).

Incidence and Parasitism

For making seasonal comparisons of the incidence and parasitism of crucifer pests, the survey was again commenced in February, when in most cases, population levels of these pests are reaching maximum proportions.

Field collections of the white butterfly and diamond-back moth were made from 20 crops in Hawke's Bay, (groups 1 to 4 inclusive) between 19 and 21 February. During the last week in February, collections were made from 40 crops situated in the Wairarapa, Manawatu, Rangitikei, and Taranaki districts (groups 5 to 12 inclusive). The results of the field collections are presented in Tables 1, 2, and 3.

In most instances only small numbers of adult butterflies were observed flying over individual crops in Hawke's Bay. The majority of the crops, Table 1, were supporting small larval populations, but in the case of crops 4D and 4E, collections of 10 minutes failed to reveal a single larva. The crops showing the most damage in this survey area were 2E, 3B, and 3C, and, as in previous seasons, the injured plants were confined mainly to the crop margins. The degree of white butterfly activity in all the other areas under survey also varied considerably, but none of the crops examined in these areas were being adversely affected by larval damage. Crops growing in groups 5 and 12 were almost entirely free from larvae. It was observed, however, that adults of the butterfly were fairly numerous over a number of crops in groups 6 to 9 inclusive. Virus-infected larvae were observed on most crops in groups 1, 2, and 3, on odd crops in groups 6 to 10 inclusive, and absent on those in groups 4, 5, and 12. The generally low incidence of white butterfly at this stage resulted in only two collections of pupae being made.

With few exceptions, diamond-back moth populations, Table 2, were found to be small with little damage occurring to the crops under examination. Only four cases of damaged crops were recorded (1B, 3B, 11A, and 11B), and in each instance the damage was classified as slight.

TABLE 2. FIELD COLLECTION RECORDS OF *P. maculipennis* INCLUDING PERCENTAGE PARASITISM* BY *A. cerophaga* AND *D. collaris* 1957–58

Group	Crop	Variety‡	Date Collected	Duration of Collection (min)	No. Collected	% Parasitism by *A. cerophaga*	% Parasitism by *D. collaris*
1	A	C	20.2.58	10	1	100.0	Nil
	B	C	,,	,,	25	88.0	,,
	C	C	,,	,,	1	100.0	,,
	D	C	,,	,,	0	—	—
	E	C	,,	,,	0	—	—
2	A	C	19.2.58	20	4	75.0	Nil
	B	C	,,	,,	3	100.0	,,
	C	C	,,	,,	0	—	—
	D	C	20.2.58	10	0	—	—
	E	C	19.2.58	,,	1	100.0	Nil
3	A	C, T	21.2.58	10	0	—	—
	B	C	,,	,,	69	44.9	Nil
	C	C	20.2.58	,,	3	100.0	,,
	D	C	,,	,,	0	—	—
	E	C	21.2.58	,,	0	—	—
4	A	C	21.2.58	10	0	—	—
	B	C	,,	,,	0	—	—
	C	C, S	,,	,,	0	—	—
	D	C	,,	,,	0	—	—
	E	C	,,	,,	0	—	—
5	A	C	24.2.58	10	4	50.0	Nil
	B	C	,,	,,	0	—	—
	C	C	,,	,,	1	Nil	Nil
	D	C, T	,,	,,	1	,,	,,
	E	C	,,	,,	3	100.0	,,
6	A	C	24.2.58	10	1	Nil	Nil
	B	C	,,	,,	1	,,	,,
	C	C	,,	,,	1	,,	,,
	D	C	,,	,,	0	—	—
	E	R	,,	,,	1	Nil	Nil
7	A	C	28.2.58	10	0	—	—
	B	R	,,	,,	1	100.0	Nil
	C	C	,,	,,	2	100.0	,,
	D	C, S	,,	,,	4	50.0	,,
	E	C	,,	,,	0	—	—
8	A	C	28.2.58	10	1	100.0	Nil
	B	C	,,	,,	2	50.0	,,
	C	C	,,	,,	0	—	—
	D	C	,,	,,	1	100.0	Nil
	E	C	,,	,,	1	100.0	,,
9	A	C	27.2.58	10	0	—	—
	B	C, S	,,	,,	7	28.6	Nil
	C	C	,,	,,	2	Nil	,,
	D	C	,,	,,	14	57.1	7.1
	E	S	,,	,,	7	42.9	Nil
10	A	C	27.2.58	10	0	—	—
	B	C, S	,,	,,	0	—	—
	C	S	,,	,,	2	Nil	Nil
	D	C, S	,,	,,	9	44.4	11.1
	E	C	26.2.58	,,	0	—	—
11	A	C	26.2.58	10	19	15.8	5.3
	B	C	,,	,,	51	74.5	5.9
	C	C, S	,,	,,	7	Nil	Nil
	D	S	,,	,,	5	,,	,,
	E	C, S	,,	,,	5	20.0	,,
12	A	C, S	26.2.58	10	2	Nil	Nil
	B	C, S	,,	,,	3	,,	,,
	C	C, S	,,	,,	1	,,	,,
	D	S	,,	,,	5	40.0	,,
	E	C, S	,,	,,	7	71.4	14.3

* Calculations based on the number of cocoons found to be parasitised when microscopically examined.
‡ C = Chou moellier; R = Rape; S = Swede; T = Turnip.

TABLE 3. PERCENTAGE PARASITISM OF *P. rapae* PUPAE BY *P. puparum* IN FIELD COLLECTIONS 1957–58

Group	Crop	Date Collected	Duration of Collection (min)	No. Collected	% Parasitism
1	A	9.4.58	10	17	100.0
2	C	19.2.58	,,	15	73.3
3	B	21.2.58	,,	106	91.5
3	D	8.4.58	,,	17	100.0
4	B	,,	,,	74	97.3
4	C	9.4.58	,,	30	96.7
7	B	10.4.58	,,	30	73.3
7	D	,,	,,	37	83.8
8	B	,,	,,	42	85.7
8	C	,,	,,	64	98.4
8	D	,,	,,	68	67.6
8	E	,,	,,	28	92.9

Aphid populations on the 60 crops examined were, in general, very small although in some instances it was observed that isolated plants, and in some cases small areas of a crop, were carrying moderate populations of this pest.

During March, reports were received of large populations of adult white butterfly over crops not covered by the survey. In one case, severe crop damage was reported. On investigating it was found that adults were in fact present in fairly large numbers over one of the crops, but also that the virus was having an appreciable effect on the larvae. It was therefore predicted with some degree of certainty, that little damage would occur. Over the crop where severe damage had been reported, adults were not particularly prevalent. This crop was growing on undulating sand-dune country, and, in addition to marginal damage, plants growing on the many knolls were also affected. With the exception of crop margins, it does appear that plants growing in these situations are more susceptible to attack than those growing in hollows or on level ground. The virus had almost completely eliminated the larval population at this stage, and no further crop damage was expected.

Crops in groups 1 to 8 inclusive were again visited in early April 1958. As was expected, where larvae of the butterfly were present earlier in the season, they were now either completely virus infected, or eliminated. Marginal damage had occurred in a number of cases, but the injured plants were now recovering and producing new growth. Random collections of pupae were made wherever possible, the results of which are presented in Table 3.

SYMPTOMS OF VIRUS INFECTION OF *P. rapae* LARVAE

Typical symptoms of virus infection of white-butterfly larvae are illustrated in Fig. 1. Healthy larvae (extreme left in Fig. 1) are active, intense green in colour, with a soft velvety appearance. In early stages of infection they become relatively inactive, flaccid, whitish in

Fig. 1.—Progressive stages in development of virus in its attack on larvae of the white butterfly, *P. rapae*.

colour, swollen in appearance with body segments showing up more prominently. During the more advanced stages of infection most larvae rupture, allowing the body contents to escape. Soon after this occurs, the diseased specimens become black in colour, and ultimately appear only as "black smudges" on the foliage (extreme right in Fig. 1) before finally being washed off by rain.

DISCUSSION

The field surveys carried out in the principal crucifer-growing areas in the North Island over the past three years, indicate that, in general, cruciferous crops can be grown in these areas with reasonable assurance that they will not be affected to any major degree by the specific insect pests of crucifers. It must be realised that these pests are potentially dangerous at all times, and even though they are normally effectively checked biologically in New Zealand, they are still capable of causing damage if conditions for breeding are favourable to them. This occurred in the 1956–57 season, particularly in regard to white butterfly, which in many districts reached significant proportions during February. The build up in population of the butterfly during the preceding months is thought to have been due primarily to the favourable breeding conditions during this period, and the fact that parasite control was inadequate in dealing with the rapid development of the pest. However, the imminent danger of a serious epidemic was prevented by the virus, which, with spectacular rapidity and effect, reduced white butterfly populations to a point where no healthy larvae could be found.

Fluctuations in population levels of white butterfly within a district are attributed mainly to variations in the time when individual crops are established in a particular district. Early-established crops will not only receive the full and concentrated impact of the first generations of the butterfly, resulting in a more rapid build up of this

pest in local areas, but they are also exposed to attack over a prolonged period, which must inevitably have some bearing on population density. Climatic conditions, which vary considerably within a district, could also influence the degree of infestation of a crop.

In spite of the high level of parasitism attained by the pupal parasite *P. puparum* at the end of the season, it does appear that the overall efficiency of this parasite is somewhat impaired by the virus. Owing to the high level of mortality in host larvae at the end of the season due to this virus, only relatively small numbers of parasitised pupae can be expected to overwinter. This results in an inadequate supply of adult parasites at the beginning of the next season to cope with the development of the butterfly, particularly if conditions for breeding are favourable to this pest. The larval parasite, *A. glomeratus,* could be similarly affected by the virus. However, since none of this latter have been recovered from the many field collections made during the three seasons. it seems probable that other factors are responsible for the complete absence of this insect in the field.

A summary of the data obtained from the survey indicates fairly clearly that the virus is a dominant factor in checking the white butterfly, particularly when there is a crowding of host larvae. It has been observed that virus-infected larvae are present even at the very onset of the season, but rarely is there a marked change in its incidence until a substantial increase in the population density of the host takes place. Generally this does not occur until the latter part of the season, but in cases where crops are carrying fairly large butterfly populations relatively early in the season, the correspondingly early development of virus in these populations appears to prevent excessive crop damage. It is apparent that there is a definite relationship between the rapidity of spread of the virus and weather conditions. In early autumn when larval populations are in many cases at their highest, warm rain showers and morning dews occur, and it is highly probable that the physical effects, particularly of rain, play an important part in spreading virus infection within individual crops. Healthy larvae probably acquire the disease either by contact with infected specimens, of by ingesting contaminated food. This being the case, moisture of any kind would tend to spread the contamination on individual plants, and in consequence, accelerate the rate of spread and degree of infection throughout the whole crop. Insects and birds are no doubt responsible to some degree for the transmission of the disease, not only within a crop, but also from one crop to another.

The generally low incidence of the diamond-back moth in the North Island can be attributed to effective control, primarily by the larval parasite, *Angitia cerophaga*, and to a lesser degree by the pupal parasite, *Diadromus collaris* (Gravenhorst). The fungous disease recorded by Robertson (1939), is also effective in checking the pest, particularly when the population density is high, and host crowding occurs. Small numbers of chalcid hyperparasites, *Eupteromalus* sp., were obtained from *Angitia* pupae during each season, but it would appear that hyperparasitism does not significantly affect the efficiency of this parasite.

A close examination of 155 individual crops made during the survey periods, revealed only one case of permanent crop damage as a result of cabbage aphid, *B. brassicae*. As was mentioned in a previous paper (Todd 1957), chou-moellier crops were in most cases used for the seasonal collections and observations. Though chou moellier is liable to aphid attack, as a fodder crop it is capable of withstanding heavy populations of this pest without serious loss of vigour and ability to recover. In the North Island, these and other brassica crops are grown mainly for the fattening of stock for export and for winter fodder. This means that a high proportion of these crops is fed off to stock prior to the following spring, resulting in a substantial reduction in the aphid population which would normally be overwintering on them. In the South Island, in addition to brassica crops grown specially for fodder, many acres of rape, chou moellier, and kale are grown each year for seed production. It could be possible for these, and perhaps residues of fodder crops, to support relatively large populations of aphids through the winter. If steps were not taken to control them before the spring, early infestation and subsequent serious damage to newly established crops could occur. Although comparative data are not available, it is apparent that, during the summer, aphid populations on crops in certain districts of the South Island are substantially higher than those found on crops in the North Island. In addition to climatic conditions, it is quite feasible that the disparity in population levels of this pest which occur between crops growing in the two islands, is influenced to some degree by the factors just discussed.

CONCLUSIONS

The results of three seasons' investigations carried out in the southern half of the North Island, show that, in spite of the relatively large numbers of adults of the white butterfly seen at times over cruciferous crops in some districts, larval populations are generally low, and damage is slight, and mainly confined to the margins. It is considered therefore that crop damage by white butterfly can only be determined by an examination of the crop and not by the number of adults seen flying over it.

During the latter part of the season it is apparent that parasitism by the pupal parasite, *Pteromalus puparum* reaches a high level, and that the virus, which is considered to be the dominant factor in checking the white butterfly, causes a heavy mortality of the larval population. There has been no evidence to show that the larval parasite, *Apanteles glomeratus,* exercises any degree of control.

In general it has been found that the diamond-back moth is not responsible for serious damage to cruciferous crops. This pest is effectively controlled primarily by the larval parasite, *Angitia cerophaga,* and to a lesser degree by the pupal parasite, *Diadromus collaris*. A fungus is also effective when the population density of the host is high.

Because of the efficiency of natural controlling factors, the use of insecticides for control of the white butterfly and diamond-back moth on cruciferous crops grown for fodder is considered to be unwarranted in the areas surveyed.

In the districts covered by the surveys, chou-moellier crops grown for fodder do not appear to be seriously affected by the cabbage aphid, *Brevicoryne brassicae*.

REFERENCES

Robertson, Phyllis L. 1939: Diamond-back Moth Investigations in New Zealand. *N.Z. J. Sci. Tech. A20:* 341-64.

Todd, D. H. 1957: Incidence and Parasitism of Insect Pests of Cruciferous Crops in Hawke's Bay, Wairarapa, and Manawatu 1955-56. *Ibid. A38:* 720-27.

———1958: Incidence and Parasitism of Insect Pests of Cruciferous Crops in Hawke's Bay, Wairarapa, Manawatu, Rantitikei, and Taranaki, 1956-57. *N.Z. J. agric. Res. 1:* 847-58.

PHOTOSENSITIVITY DISEASES IN NEW ZEALAND

XVI. IMPROVED PROCEDURE FOR THE BEAKER TEST FOR FACIAL-ECZEMA TOXICITY

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(*Received for publication, 5 January 1959*)

Summary

A simpler and much more rapid procedure for the "beaker test" is described. The new method eliminates interference due to pennyroyal. Comparison against the original procedure suggests that the new method is the more sensitive in detecting the white substance which is the basis of the test.

Introduction

The procedure for the "beaker test" described by Perrin (1959) requires at least 36 hours. Obviously a method which gives a result more quickly, preferably within the day of collection of the sample, would be a considerable advantage in facial eczema investigations. Various stages in the method were, therefore, examined, and the following points were established.

1. The "beaker test" substance can be extracted from pasture by cold percolation with a small volume of acetone instead of continuous hot extraction with ether.
2. Evaporation, methanol solution, extraction with petrol ether, and transfer to ether/acetone, are not necessary before chromatography, provided a high-activity alumina is used.
3. Use of high-activity alumina with acetone removes the substance present in pennyroyal which interfered with the original test on pastures containing this weed.

From these observations the following rapid "beaker test" procedure was developed.

Description of Procedure

The adsorbents used are:

Alumina: B.D.H. alumina for chromatography; or recovered alumina of activity 1–2. To recover used alumina it is heated 1–2 days in a muffle at 550°c, cooled, washed several times with water and dried at 140°c for several days. When thoroughly dry it is screened, passing a mesh of 0.2 mm.

Adsorbtive Carbon: Darco G 60, 1 part; Celite 545, 2 parts by weight; dried at 120°c.

Procedure for 50-g Samples

A 50–g sample of dried ground grass is packed into a tube 8 × 1.3 in. and extracted, under suction, with four 25–ml portions of acetone.

An alumina column 9 × 0.5 in. and a carbon column 13 × 0.5 in. are prepared in acetone and the two joined by standard joints, with the alumina column uppermost. Alumina is added as an acetone slurry from a plastic wash bottle and settled by tapping the outside of the tube. The carbon-celite mixture is also added as a slurry but consolidated by suction. The extract (usually about 50 ml) is poured into a separating funnel fitted into the alumina column and a pressure of about 10 lb per sq. in. applied by blowing ball or electric pump. The funnel tap is held in place by an elastic band, and the two columns by spring fasteners.

When almost all of the extract has entered the alumina column, acetone is added to the separating funnel and pressure is again applied. The first 75 ml of eluate is discarded, the next 75 ml is placed in a squat 100-ml beaker, and the final 25 ml in a 50-ml beaker. Both of these portions are evaporated before a fan. A white deposit on the walls of the beaker indicates a positive result. Usually all of the white substance is found in the first beaker, but occasionally some is carried over into the second beaker.

With this procedure tests can be completed within four hours of receiving the sample, and one operator can handle over 20 samples per day.

Procedure for Smaller Samples

For routine tests it is usual to use 50-g samples, to ensure reasonable amounts of white deposit at low levels, but where only small quantities are available, satisfactory tests can be carried out with suitable modification of the apparatus.

For 10-g samples, a percolation tube of $\frac{3}{4}$ in. diameter is used, with 20 ml acetone. The alumina column (2 × 0.5 in.) and carbon column (3 × 0.5 in.) are prepared in one tube and separated by a small wad of cotton wool. The first 20 ml of eluate is discarded, the next 20 ml fraction is placed in a 30-ml beaker, and the final 10 ml in a 20-ml beaker.

For 5-g samples, both columns are packed in the same 0.5 in. diameter tube, the height of the alumina being 1.5 in., and of the carbon, 2.0 in. The volume of eluate discarded is 15 ml, and two fractions of 20 ml and 10 ml are collected.

Standards

A series of standard beakers was prepared from samples representative of the "beaker test" gradings. These beakers were covered with plastic film to protect the deposit from dust. The samples from which they were prepared are held in cool storage, so that fresh standards can be made from time to time. The amount of deposit obtained from these standards has decreased slightly after 12 months, but not sufficiently to alter the grading. These standards are graded 0 to 3. By making a series of dilutions of grade 3 grass with beaker-test negative grass and testing these mixtures, it was found that grade 1 corresponded to approximately 10% and grade 2 to 40% of grade 3.

Because the amount of deposit often obviously lies between these grades an extended scale from 1 to 6 is proposed. On this new scale "Grade 1" would correspond to a faint trace of deposit below 1 on the old scale; grade 2 to the old grade 1; grades 4 and 6 to the old grades 2 and 3. This extended scale reduces the assessment error for samples intermediate between the standards. It is doubtful, however, in view of variability in guinea-pig response and other factors, discussed in another paper (Clare and Sandos, in preparation) whether it has any advantage in correlating beaker test with toxicity. The new scale is being used in recording samples cut in 1958, but the old system will, for convenience, be retained in further discussion in this paper.

Over a set of 330 tests independent comparisons with the standards were made by two observers. For 64% two observers gave the same grading, for the remainder they differed by 1 grade, except for two samples in which the difference was 2 grades. In 8.5% of these tests the observers disagreed in discrimination between positive and negative. Similarly, for a series of 100 tests, 3 observers agreed in 62% and differed by 1 grade in the remainder, but with 3 observers the failure to agree in discriminating between positive and negative was higher (18%).

For a series of 215 samples tested in duplicate and matched against standards by one operator, the duplicate tests agreed in 79%, and differed by 1 grade in the rest. For 5% of these samples one test was graded 1 and the other negative.

It is apparent that even when tests are compared against standards an uncertainty of $\pm$ 1 grade can be expected in about one third of the samples. The difference of 1 grade may in many cases be accounted for by the difficulty, where the amount of deposit is intermediate between grades, of deciding whether to allot the lower or the higher value.

COMPARISON OF NEW AND OLD METHODS

One hundred and seventy nine samples which had been tested by the original method (Perrin 1959) 3–6 months earlier, were retested by the new procedure. All tests by the new procedure were made in duplicate, but most of those by the old method had been done only as single determinations. For two-thirds of the new tests comparison with standards was made by two or more observers. Where observers or duplicates disagreed the grading used was that nearest to or next above the mean.

Results of this comparison of the two procedures are as follows:

No. giving same result by both methods	101	(57 %)
No. giving higher grading by new method (+ 1, 33; + 2, 6)	39	(21.5%)
No. giving lower grading by new method (— 1, 26; — 2, 11; — 3, 2)	39	(21.5%)
No. negative by old procedure, positive by new	20	
No. positive by old procedure, negative by new	6	

Similar results were obtained for a group of 25 samples tested at the same time by both procedures in duplicate. Although the proportion of samples on which the two methods did not agree (43%) is high, it is no greater than might be expected considering the uncertainty of ± 1 grade previously indicated. The comparison does not show that one method is appreciably more sensitive than the other, apart from the difference in proportion of negative samples. It appears that slightly higher yields of the white deposit are obtained by the new procedure.

The "beaker tests" obtained by the new method on this series of 179 samples were compared with guinea pig toxicity, the samples being divided into the groups described in a later paper by Clare and Sandos. The results closely paralleled those obtained by the old method, except for the group "cut before Mar. 26", in which the proportion of "beaker test" positive samples which were also toxic was 11% lower by the new method. This again appears to be a consequence of the slightly higher sensitivity of the new method.

Removal of Interfering Substances

In the method originally described by Perrin (1959) two plants were found to give false positive "beaker tests", pennyroyal and red clover. Interference due to the latter was traced to formononetin (White 1958) and is of little consequence since it occurred only in spring pastures. The effect of pennyroyal is much more serious because it is common in summer and autumn pastures. The use of acetone with high-activity alumina in the new procedure has eliminated interference from this source. Samples containing as much as five per cent by weight of pennyroyal have given negative "beaker tests" by this method.

Acknowledgement

We are indebted to Miss G. Hughes and Messrs. A. Fyvie and H. de Langen for carrying out some of the experiments involved in establishing this method.

References

Perrin, D. D. 1959: *N.Z. J. agric. Res. 2:* 266-73.
White, E. P. 1958: *Ibid. 1:* 859-65.

Addendum

Since this paper was prepared for publication, isolation of the beaker-test substance from *Sporidesmium bakeri* has provided a source of purified material from which standards can be prepared. For this purpose the beaker-test substance (m.p. 245°c uncorr.) was dissolved in a small amount of chloroform, added to 75-ml portions of acetone to give appropriate dilutions, and the acetone evaporated as in the routine tests. The weights of beaker-test substance found to correspond to the 6 grades proposed in this paper were:

Grade 1, < 0.1 mg; grade 2, 0.1 mg; grade 3, 0.2 mg; grade 4, 0.3 mg; grade 5, 0.5 mg; grade 6, 0.7 mg.

COMPARISON OF FAECAL PIGMENTS AND FAECAL NITROGEN AS DIGESTIBILITY INDICATORS IN GRAZING CATTLE STUDIES

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(*Received for publication, 2 February 1959*)

Summary

Digestibility data and faecal pigment and nitrogen concentrations are reported for 37 consecutive weekly trials with cows fed cut pasture herbage.

The formula of Reid *et al.* (1952) was in general not satisfactory for predicting dry-matter digestibility from faecal pigment concentrations.

For estimating the feed/faeces (organic matter) ratio, faecal nitrogen, with a prediction error of 8%, provided a more reliable index than faecal pigments (error 11%), the prediction relationship in both cases being curvilinear. However the use of faecal pigments in addition to faecal nitrogen led to a small but significant reduction (to 7%) in the error of prediction.

Introduction

In the determination of digestibility, and the related quantity feed/faeces ratio required in the indirect estimation of forage consumed by the grazing animal, the faecal index method offers distinct advantages over any method requiring sampling of forage. Two faecal indexes are now in common use, the faecal pigments of Reid *et al.* (1952) and the faecal nitrogen of Lancaster (1949, 1954).

Although each method is subject to some error, few studies designed to compare the prediction errors have been published. Raymond *et al.* (1954) using sheep as test animals found both methods to yield comparable errors in the estimation of digestibility. A similar project using dairy cows was begun at this Station, but was postponed pending investigation of certain analytical difficulties encountered in the estimation of faecal pigment concentration. The results of this investigation suggested certain modifications which would increase the precision of the analytical technique (Lancaster and Bartrum 1954). The main project to compare the pigment and nitrogen methods was reinitiated in August 1956, and the results obtained from the series of digestion trials terminating in May 1957 are here presented.

The objectives of the experiment were:

1. To test under New Zealand conditions the formula of Reid *et al.* (1952) for estimating the digestibility of pasture herbage from the concentration of faecal pigments.
2. To compare faecal pigments and faecal nitrogen as indicators of the feed/faeces ratio.

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Experimental Procedure

Six dry Jersey cows were continuously fed weighed amounts of harvested pasture herbage from August 1956 until May 1957. The herbage, primarily ryegrass/white-clover mixture with varying amounts of Yorkshire fog and cocksfoot, was sampled and analysed each week for dry matter and ash content. From 31 August 1956 to 16 May 1957 the digestibility of the forage was determined, faeces from three of the six cows each week being collected in bags (Ballinger and Dunlop 1946), weighed, and analysed. Each week the cows were alternated for faeces collection.

Composite samples of dried and of raw faeces representative of each animal's weekly output were prepared from the contents of the collection bags. The raw samples were stored in air-tight jars in a refrigerator until analysed, no preservative being used. Maximum elapsed time between defaecation and analysis was four weeks, a time shown to be without effect on the constituents determined.

The data presented in this paper relate to 37 consecutive weekly trials. For evaluating the formula of Reid *et al.* (1952) faecal pigment concentrations and digestibilities have been expressed on a dry-matter basis. For comparing estimates of feed/faeces ratio derived from the several faecal indexes investigated all data were expressed on an organic-matter basis.

Chemical Analysis

Nitrogen was estimated on both undried and oven-dried (100°C) faeces, by the Kjeldahl procedure as modified by White *et al.* (1948). The results were expressed as percentage of faeces organic matter.

Ash was determined by ignition of oven-dried faeces samples in a muffle furnace at 580°C for 1½ hours.

Faecal pigments were determined in the raw faeces as follows: The sample was vigorously macerated with distilled water until a slurry containing 8–10% dry matter was produced. A ten-gramme (approx.) sample was weighed in a porcelain dish for dry-matter determination and subsequent ash determination. A one-gramme (approx.) sample was weighed on filter paper and macerated with 200 ml 85% acetone for two minutes. The contents of the macerating jar were transferred to a 1000-ml volumetric flask and made to volume with 85% acetone. After equilibrating for about 30 minutes, the contents of the flask were mixed, and a few millilitres filtered through No. 1 filter paper. The optical density was immediately read on a Beckman spectrophotometer at 406 μ and 415 μ. The readings were then scaled up to a basis of 100 g faeces (dry matter or organic matter) to give faecal pigments per cent.

Flasks and blending jars were covered with black cloth, and manipulations were carried out in complete darkness wherever possible. The time lapse between weighing the sample and reading the optical density was 30 to 60 minutes. The mean values obtained by the modified procedure were similar to those resulting from the procedure of Reid *et al.* (1952) but the modified procedure yielded more consistent results.

From 25 October 1956 until the completion of the experiment (trials 8 to 37) faecal pigments were also determined after extracting with 85% acetone containing 1% oxalic acid, using the procedure outlined above. The optical density was read at 415 μ.

All chemical determinations were carried out on duplicate samples, the mean value being accepted.

RESULTS AND DISCUSSION

Goodness of Fit of Formula of Reid et al.

Reid *et al.* (1952) established the empirical relationship

$$D = 32.74 + 0.0168Z + 8.47 \log Z$$

where D = dry matter digestibility (%)

and Z = units of chromogen (wave length 406 μ) per gramme faeces dry matter.

As defined by Reid *et al.*, units of chromogen are related to the percentage transmitted light, and hence to the optical density, of the substance in an 85% acetone extract. To a sufficiently close approximation

$$Z = 287X$$

where $\frac{X}{100}$ = optical density (at 406 μ) of 1 g faeces dry matter in 1000 ml 85% acetone extract.

i.e. X = faecal pigments % (dry-matter basis).

From the above two equations we find

$$D = 53.56 + 4.822X + 8.47 \log X$$

The trial means of the digestibility coefficients and of the faecal pigments at 406 μ, both on a dry-matter basis, are shown in Table 1, together with the digestibility coefficients predicted using the above formula. The trend of observed and predicted digestibilities as the season progressed is illustrated in Fig. 1. It is clear that, in general, the fit is far from satisfactory, except in the two periods of highly digestible pasture (above 75%) in the spring and late autumn. During the summer period of falling digestibility the formula substantially underestimated digestibility; over the autumn period when digestibility was very low (about 50%) and subsequently rising, on the other hand, the predicted values were materially higher than those observed.

It must be concluded therefore that the relationship derived from studies in the north-east United States cannot be applied to New Zealand pastures. Although no satisfactory explanation can be offered at this stage, it is clear that further research into the problem is needed. The generally systematic trend in the differences between predicted and observed digestibilities (Fig. 1) suggests that a useful relationship could be derived from these and similar data for the prediction of digestibility. However, attention will be focussed rather on prediction of the related quantity, the feed/faeces ratio, which is of more direct interest at this Station in the estimation of pasture intakes.

TABLE 1. DIGESTIBILITY DATA
Trial means only

Trial	Concluding Date (1956-57)	Faecal Pigments % at 406μ (X)	Dry-matter Digestibility (%)	
			Predicted (D)*	Observed
1	6/ 9	3.69	76.2	76.5
2	13/ 9	4.19	79.0	78.5
3	20/ 9	3.95	77.7	76.4
4	27/ 9	3.21	73.3	75.8
5	4/10	3.89	77.3	76.5
6	11/10	4.38	80.1	78.8
7	18/10	3.46	74.8	78.5
8	25/10	2.94	71.7	77.1
9	1/11	2.34	68.0	74.2
10	8/11	1.72	63.8	72.8
11	15/11	2.09	66.4	72.9
12	22/11	1.89	65.0	73.3
13	29/11	1.69	63.6	72.3
14	6/12	1.98	65.6	73.2
15	13/12	1.32	60.9	71.2
16	20/12	1.15	59.6	70.1
17	27/12	1.60	63.0	68.9
18	3/ 1	1.74	64.0	67.7
19	10/ 1	1.63	63.2	69.1
20	17/ 1	1.37	61.3	68.4
21	24/ 1	1.09	59.1	62.6
22	31/ 1	1.18	59.9	65.1
23	7 /2	1.01	58.5	69.6
24	14/ 2	0.71	55.7	57.9
25	21/ 2	0.53	53.8	50.2
26	28/ 2	0.70	55.6	49.4
27	7/ 3	0.76	56.2	48.5
28	14/ 3	0.74	56.0	51.1
29	21/ 3	1.21	60.1	58.4
30	28/ 3	1.42	61.7	55.0
31	4/ 4	3.08	72.6	68.3
32	11/ 4	3.17	73.1	68.0
33	18/ 4	3.39	74.4	75.4
34	25/ 4	3.70	76.2	78.0
35	2/ 5	3.89	77.3	77.7
36	9/ 5	4.98	83.5	79.6
37	16/ 5	4.68	81.8	78.1

* $D = 53.56 + 4.822X + 8.47 \log X$

Comparison of Faecal Pigments and Faecal Nitrogen in Predicting Feed/Faeces Ratio

Five possible prediction variables were considered for estimating the ratio (y) of organic matter (o.m.) consumed to o.m. excreted, namely faecal pigments per 100 g o.m. at 415 μ (x_1), at 406 μ (x_4) and in addition, in trials 8–37, at 415 μ after extraction with 1% oxalic acid solution (x_5): and nitrogen per 100 g faeces o.m. from undried faeces (x_2) and from oven-dried faeces (x_3). The data are presented in the Appendix.

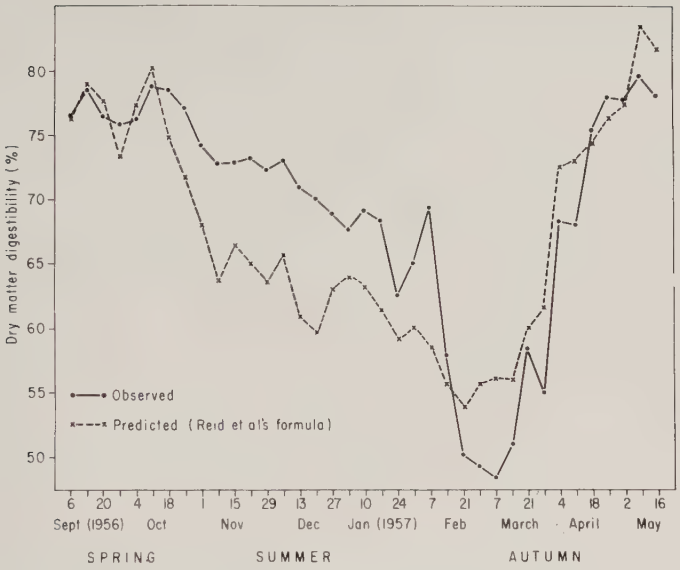

Fig. 1.—Seasonal trend of observed and predicted digestibilities.

For all variables the total variation may be classified into two portions, namely between trials and within trials. A sample covariance analysis, of y with x_2, is shown in Table 2. Here, as with all the other variables, it is found that differences between trials, reflecting change in feed quality (and possibly quantity) as the season progressed, account for most of the total variation, differences between cows consuming similar feed being small.

TABLE 2. COVARIANCE AND REGRESSION ANALYSIS
Feed/Faeces o.m. ratio (y) on Nitrogen % Undried Faeces o.m. (x_2)
(Mean squares/products only)

Source of Variation	(x_2^2)	(yx_2)	(y^2)	Deviations from Regression
Between trials (36 d.f.)	2.166	2.722	3.675	.261**
Within trials (74 d.f.)	.023	−0.0005	.037	.037
Total (110 d.f.)	.724	.891	1.227	.134**

** Regression highly significant ($P < 0.01$)

It is apparent also from Table 2 that there exists a significant relationship between y and x_2 in respect of the variation between trials, but not within trials. A similar general pattern is found in respect of the other variables. The trial means of y are plotted against those of

x_1, x_2, and x_3 in Figs. 2, 3a, and 3b. Corresponding graphs for x_4, x_5 are very similar to Fig. 2.

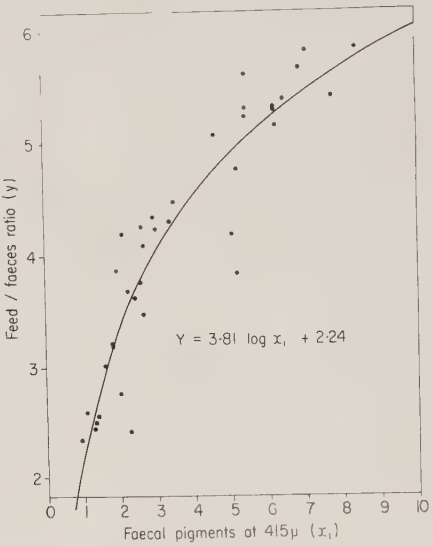

Fig. 2.—Relationship of feed/faeces ratio and pigments (415 μ).

In deriving prediction formulae and their errors for subsequent application the problem arises as to how best to combine the two contributing sources of variation, between and within trials (compare Lancaster, 1954). If application were to be to future trial means based on three cows then analysis of the present series of trial means would be appropriate. This would not however be the case if it were intended to apply the results to individual animals or to the means of more (or less) than three cows; for example n cows. In theory one should weight the between and within trial components of variance and covariance in the ratio of 1: $\frac{1}{n}$ and then derive regression estimates. In considering application to individual animals ($n = 1$), since the within-trial variation is small and each trial contains the same number of cows, use of the "total" sums of squares and products introduces very little bias (as compared with the variance and covariance component method). The regression analyses based on the "total" variation are summarised in Table 3. All the constants shown (first three columns) are significantly different from zero* and are in close agreement with corresponding estimates from variance component analysis.

The relationship between the feed/faeces ratio (y) and the several predictive variables must be deemed curvilinear rather than linear, as indeed is suggested by Figs. 2 and 3. As judged by the residual standard deviation (from the fitted regression line) and coefficient of variation (see

* The derived tests of significance are subject to a bias analogous to that in the estimates themselves, but this is also considered to be negligible in the present instance.

TABLE 3. SUMMARY OF REGRESSION ESTIMATES
(based on "total" variation)

Trials	Predictand : y = Feed/Faeces Ratio Predictor (Mean values in brackets)		Regression Coefficients Linear	 Quadratic	Intercept	Residual s.d.	Coeff. of Variation %
1–37 (mean y = 4.14)	Pigments 415μ (x_1 = 3.77)	Linear	0.46		2.39	.49	11.9
		Quadratic	0.93	−0.055	1.64	.45	10.9
		Logarithmic	3.81		2.24	.44	10.6
	Nitrogen, undried faeces (x_2 = 3.70)	Linear	1.23		−0.41	.37	8.8
		Quadratic	3.64	−0.315	−4.79	.31	7.4
		Logarithmic	10.57		−1.74	.32	7.8
	Nitrogen, dried faeces (x_3 = 3.48)	Linear	1.19		—	.40	9.6
		Quadratic	4.32	−0.420	−5.51	.32	7.7
		Logarithmic	10.34		−1.33	.35	8.4
	Pigments 406μ (x_4 = 3.07)	Linear	0.56		2.43	.48	11.7
		Quadratic	4.10	−0.072	−7.55	.44	10.6
		Logarithmic	3.67		2.66	.43	10.3
8–37 (mean y = 3.83)	Pigments 415μ + 1% oxalic acid (x_5 = 3.57)	Linear	0.40		2.38	.52	13.5
		Quadratic	0.86	−0.048	1.57	.47	12.3
		Logarithmic	3.71		2.03	.45	11.8
	Pigments 415μ (x_1 = 3.19)	Linear	0.44		2.43	.51	13.4
		Quadratic	0.58	−0.016	2.21	.50	13.1
		Logarithmic	3.55		2.30	.44	11.6

Table 3) the simple logarithmic regression is slightly "better" than the quadratic regression for the pigments (x_1, x_4, x_5) and conversely for faecal nitrogen (x_2, x_3). However the difference is in most cases small and the logarithmic regression is to be preferred on the grounds of simplicity, with two descriptive constants only, and because the predicted value steadily increases with x (the quadratic curve in Fig. 3b, for example, has a maximum value 5.60 when x_3 = 5.14, and then declines).

Turning now to comparison of the several variables as predictors of y it is evident from Table 3 that faecal nitrogen (x_2, x_3) leads to materially smaller prediction errors than do faecal pigments. Further, it appears that the nitrogen content of undried faeces (x_2) is a rather better predictor than that of oven-dried faeces (x_3). There is little apparent difference between faecal pigments determined at 415 μ and at 406 μ. The effect of adding oxalic acid can be gauged only from trials 8–37, the relevant results being shown in the lower part of Table 3. It may be concluded that the addition of oxalic acid confers no advantage in the prediction of y when readings are taken at 415 μ.

Although faecal nitrogen has been shown in these data to be superior to faecal pigments in the prediction of the feed/faeces ratio, it

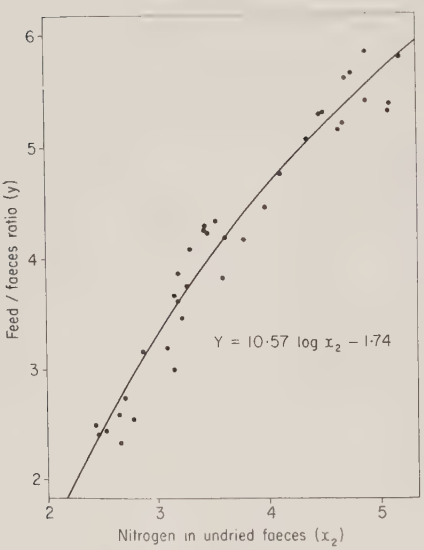

Fig. 3a

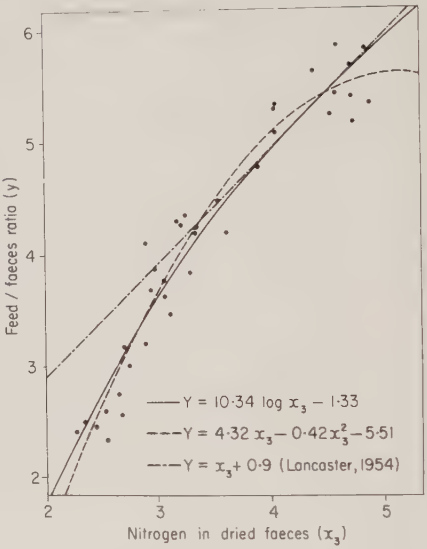

Fig. 3b

Fig. 3.—Relationship of feed/faeces ratio and nitrogen in (a) undried faeces; (b) dried faeces.

is possible that the use of both measures may be advantageous. To investigate this, multiple regressions (based on the "total" variation) were computed for y on x_1 or x_4 in addition to x_2 or x_3. The analysis using logarithms of the predictive variables is summarised in Table 4. The significance of the partial regressions on log pigments reflects a significant reduction in the residual mean square, and hence in the error of prediction, over that resulting from the use of log faecal nitrogen alone. In absolute terms however the reduction in the error (standard deviation) is small, approximately 6%. Whether this increased precision would warrant the determination of faecal pigments in addition to faecal nitrogen in practice is open to question. It may be noted that when the analysis was based on the untransformed variables, the partial regressions on pigments were not significant when undried faeces nitrogen was used and barely significant with nitrogen from dried faeces. The resulting errors were in all cases substantially greater than those shown in Table 4, based on logarithms of the variables.

The small variation observed between cows within trials suggests that the present results, appropriate strictly to individual animals, would apply satisfactorily also to the means of groups of animals consuming the same feed. For groups of say n cows, the residual variance should however be reduced by approximately 0.037 $(1 - \frac{1}{n})$—see Table 2.

In many applications it is required to derive, from given faeces o.m. outputs, an estimate of the intake of digestible organic matter. In this case the appropriate input/output ratio (see Lancaster, 1954) is $\frac{\text{feed o.m.-faeces o.m.}}{\text{faeces o.m.}}$ that is y — 1 in the terminology of this paper.

TABLE 4. Summary of Multiple Regression Analysis
Feed/faeces (y) on log nitrogen and log pigments

Predictors		Coefficient* of		Intercept	Deviations from Regression	
Nitrogen	Pigments	Log Nitrogen	Log Pigments		Mean Square	s.d. (coeff. of variation)
Undried faeces (x_2)	—	10.57		−1.74	.105	.323 (7.8%)
	415μ (x_1)	7.96	1.06	−0.82	.093	.305 (7.4%)
	406μ (x_4)	7.91	1.03	−0.68	.094	.306 (7.4%)
Dried faeces (x_3)	—	10.34		−1.33	.120	.347 (8.4%)
	415μ (x_1)	6.36	1.55	—	.105	.324 (7.8%)
	406μ (x_4)	6.77	1.37	—	.104	.323 (7.8%)

* All values shown are highly significant ($P < 0.01$)

The appropriate prediction formulae are easily derived from those presented here (merely by subtracting unity). The errors will be unchanged but the coefficient of variation will of course be increased.

It is of interest to compare the present findings with those of Lancaster (1954) in which the feed/faeces ratio (o.m. basis) was related to nitrogen percentage on an o.m. basis determined from dried faeces, that is to x_3 in the present notation. In these earlier studies there was little evidence of non-linearity of the regression, and the derived (linear) prediction formula was found to be, approximately,

$$Y = x_3 + 0.9 \pm 0.39 \ (9.1\%)$$

This line is shown in Fig. 3b. Although fitting the present data moderately well for higher values of the feed/faeces ratio, that is for the more digestible pastures, it diverges markedly at lower values. From Table 3 it may be noted that the best linear prediction relation from the present data is

$$Y = 1.19\ x_3 \pm 0.40 \ (9.6\%)$$

However, the evidence strongly favours use of a quadratic or logarithmic regression formula. In regard to the earlier series of trials it should be borne in mind that there were no mixed pastures with o.m. digestibility less than 67% (feed/faeces ratio = 3) whereas in the present series the digestibility in trials 24–30 inclusive (mid February to end March) fell appreciably below this value. It is possible also that a different relationship exists for paspalum, included in the earlier trials, as compared with normal mixed pastures. Apart from the paspalum data the previous series shows satisfactory agreement with the trials here reported.

To summarise the results of this section the "best" formulae for the prediction of feed/faeces o.m. ratio (Y) are, from Tables 3 and 4:

1. $Y = 10.57 \log x_2 - 1.74 \pm 0.32 \ (7.8\%)$
2. $Y = 4.32\ x_3 - 0.42\ x_3^2 - 5.51 \pm 0.32 \ (7.7\%)$
   or $Y = 10.34 \log x_3 - 1.33 \pm 0.35 \ (8.4\ \%)$
3. $Y = 3.81 \log x_1 + 2.24 \pm 0.44 \ (10.6\%)$

4. $Y = 7.96 \log x_2 + 1.06 \log x_1 - 0.82 \pm 0.31$ (7.4%)

where x_2, x_3 measure faecal nitrogen in undried and dried faeces respectively, and x_1 measures faecal pigments at 415 μ.

References

Ballinger, C. E.; Dunlop, A. A. 1946: *N.Z. J. Sci. Tech. A27:* 509-20.

Lancaster, R. J. 1949: *N.Z. J. Sci. Tech. A31:* 31-8.

————1954: *Ibid., A36:* 15-20.

Lancaster, R. J.; Bartrum, Margaret P. 1954: *N.Z. J. Sci. Tech. A35:* 489-96.

Raymond, W. F.; Kemp, C. D.; Kemp, A W; Harris, C. E. 1954: *J. Brit. Grassl. Soc. 9:* 69-82.

Reid, J. T.; Woolfolk, P. G.; Hardison, W. A.; Martin, C. M.; Brundage, A. L.; Kaufman, R. W. 1952: *J. Nutr. 46:* 255-70.

White, E. P.; Thompson, F. B.; Brice, N. 1948: *Analyst 73:* 146-8.

APPENDIX
EXPERIMENTAL DATA—ORGANIC-MATTER BASIS

Trial	Faeces Nitrogen (%)		Faecal Pigments (%)			Feed/faeces Ratio Y
	Undried Faeces x_2	Faeces Dried x_3	at 415μ x_1	at 406μ x_4	at 415μ + oxalic acid x_5	
1	5.29	5.00	5.84	4.90		5.09
	4.95	4.89	6.14	5.14		5.79
	5.00	4.84	6.65	5.31		5.09
2	5.54	5.02	6.78	5.64		5.48
	4.90	4.63	7.06	5.79		6.07
	5.10	4.92	7.35	6.05		5.87
3	4.72	4.72	6.55	5.49		5.22
	4.50	4.66	6.16	4.98		5.03
	4.66	4.84	6.00	5.15		5.23
4	4.78	4.59	5.30	4.44		5.07
	4.57	4.47	5.23	4.34		5.41
	4.67	4.56	5.71	4.74		5.19
5	5.12	4.82	6.35	5.41		5.64
	4.94	4.71	6.10	5.16		4.99
	5.21	4.69	6.97	5.86		5.52
6	4.81	4.70	6.76	5.69		5.69
	4.62	4.70	6.83	5.65		5.45
	4.81	4.78	6.96	5.84		5.84
7	4.50	4.46	5.26	4.38		5.85
	4.78	4.27	5.58	4.65		5.50
	4.80	4.48	5.49	4.55		5.48
8	4.35	4.10	4.44	3.57	4.23	4.77
	4.42	4.08	4.52	3.71	4.77	5.31
	4.25	4.00	4.88	3.93	4.88	5.13
9	3.86	3.53	3.65	2.86	4.12	4.35
	4.05	3.66	3.81	2.95	4.12	4.38
	4.03	3.43	3.96	3.07	4.26	4.68
10	3.25	2.84	2.59	2.04	3.09	3.94
	3.41	2.92	2.60	2.03	3.24	4.12
	3.24	2.94	2.83	2.18	3.40	4.22
11	3.45	3.11	3.18	2.48	3.54	4.27
	3.40	3.10	3.41	2.61	3.66	4.27
	3.44	3.31	3.57	2.70	3.89	4.35
12	3.56	3.28	2.87	2.30	3.14	4.30
	3.55	3.23	2.93	2.34	3.15	4.34
	3.48	3.23	2.95	2.36	3.50	4.38
13	3.43	3.14	2.56	2.06	3.02	4.27
	3.56	3.33	2.59	2.12	2.99	4.28
	3.30	3.16	2.69	2.17	3.10	4.21
14	3.52	3.34	2.79	2.41	3.39	4.25
	3.35	3.32	3.20	2.54	3.64	4.13
	3.48	3.40	3.05	2.63	3.63	4.33
15	3.55	3.36	2.09	1.71	2.30	4.20
	3.68	3.29	2.11	1.76	2.46	4.04
	3.60	3.37	2.15	1.77	2.76	4.34
16	3.24	2.95	1.91	1.55	2.10	3.70
	3.28	3.10	1.93	1.39	2.23	4.03
	3.06	2.90	1.93	1.43	2.40	3.88
17	3.25	3.09	2.44	1.98	2.74	3.52
	3.27	3.12	2.40	1.98	2.75	3.78
	3.05	2.98	2.44	1.98	2.69	3.55
18	3.25	3.12	2.59	2.10	2.83	3.56
	3.28	3.10	2.72	2.18	3.03	3.43
	3.15	3.11	2.64	2.12	2.80	3.42

APPENDIX (Continued)

	x_2	x_3	x_1	x_4	x_5	Y
19	3.26	3.11	2.52	2.02	2.79	3.74
	3.36	3.06	2.62	2.10	2.93	3.77
	3.18	3.01	2.57	2.08	2.80	3.77
20	3.14	2.92	2.19	1.74	2.38	3.58
	3.26	3.06	2.24	1.78	2.37	3.89
	3.07	2.84	2.27	1.77	2.41	3.56
21	3.04	2.75	1.79	1.41	2.00	3.20
	2.77	2.69	1.74	1.39	1.93	3.08
	2.83	2.67	1.83	1.42	2.02	3.22
22	3.22	2.98	1.79	1.47	2.03	3.16
	3.01	2.77	1.79	1.45	1.98	3.23
	3.04	2.92	1.78	1.46	1.95	3.22
23	3.42	2.62	1.57	1.26	1.94	2.96
	3.11	2.73	1.64	1.31	1.97	2.98
	2.92	2.87	1.61	1.29	1.88	3.06
24	2.70	2.43	1.04	0.82	1.31	2.56
	2.66	2.59	1.16	0.91	1.42	2.68
	2.60	2.54	1.06	0.83	1.31	2.53
25	2.69	2.55	0.88	0.66	1.17	2.21
	2.70	2.53	0.94	0.70	1.27	2.39
	2.61	2.53	0.91	0.68	1.22	2.40
26	2.54	2.32	1.28	0.94	1.58	2.46
	2.56	2.50	1.31	0.95	1.56	2.41
	2.50	2.47	1.25	0.93	1.52	2.47
27	2.84	2.75	1.42	1.12	1.50	2.50
	2.78	2.65	1.36	1.09	1.41	2.65
	2.73	2.59	1.33	1.09	1.44	2.52
28	2.38	2.27	1.30	1.00	1.42	2.39
	2.47	2.34	1.30	0.98	1.46	2.62
	2.48	2.40	1.27	0.99	1.46	2.48
29	2.77	2.70	2.02	1.54	2.41	2.77
	2.63	2.58	1.98	1.46	2.32	2.68
	2.72	2.65	2.00	1.53	2.32	2.78
30	2.29	2.17	2.20	1.63	2.49	2.20
	2.65	2.39	2.38	1.79	2.70	2.28
	2.45	2.23	2.22	1.67	2.52	2.74
31	3.52	3.30	5.35	4.24	6.16	3.59
	3.85	3.26	5.05	4.17	5.71	4.06
	3.41	3.32	5.09	4.10	5.87	3.83
32	4.04	3.89	5.65	4.66	5.91	4.06
	3.32	3.26	4.99	4.10	5.38	3.89
	3.98	3.71	4.56	4.58	5.94	4.61
33	4.28	4.03	5.39	4.46	5.58	5.05
	3.90	3.70	5.14	4.26	5.41	4.62
	4.15	3.96	5.04	4.27	5.40	4.62
34	4.76	4.19	5.65	4.67	5.94	5.16
	4.39	3.98	5.98	4.94	6.49	5.39
	4.31	4.02	5.65	4.71	6.18	5.37
35	4.52	4.20	6.09	4.95	6.90	5.22
	4.43	3.94	6.23	5.06	6.95	5.22
	4.46	4.06	6.32	5.11	6.95	5.43
36	4.86	4.72	8.20	6.59	8.88	5.62
	4.92	4.43	8.70	6.94	9.58	5.80
	4.82	4.66	8.25	6.66	9.11	6.09
37	5.18	4.77	7.70	6.36	8.30	5.11
	4.68	4.45	7.75	6.19	8.65	5.74
	4.78	4.55	7.72	6.19	8.72	5.37

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